BAMBOO CHARCOAL

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Promotion of the Utilization of Bamboo from Sustainable Sources in Thailand

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Bamboo Charcoal

Introduction

This report describes bamboo preparation and carbonization research performed on five species of Japanese bamboo. The report will explain this research and the worthwhile yield improvements which can be gained by certain pre-treatments prior to carbonization. While many technical terms are used in this report, great efforts were made in the writing of this report that it may be understood by a wide range of people.

Chapter I : The Process of Carbonization with Raw Bamboo

In basic terms, carbonization is the process of turning organic matter into carbon by using heat. Initially, when heat is applied to organic matter, dehydration occurs. This is followed by several chemical reactions including polymerization-condensation, cleavage of functional groups and amortization. These chemical reactions do not necessarily happen in this order, and in fact often overlap each other. When the organic matter reaches 450°C, the actual carbonization begins.

Bamboo is a woody system substance, and when these chemical reactions occur during carbonization, the substance does not melt or lose its shape; instead the carbonization continues and the bamboo maintains its solid condition. The finished product is simple carbon in solid form. For this reason we call this whole process 'solid phase reaction'.

Also, with bamboo the 'solid phase reaction' does not change all of its micro tissue, and the carbonized substance retains much of its original microstructure. With experience it is therefore possible to select a particular type of carbonized microstructure, by selecting the correct bamboo as the raw material to be carbonized.

Temperature control is an important factor in the carbonization process. In recent years with the advent of the semiconductor chip, it has revolutionized the technology of heat control. In many parts of the world, industry has adopted this new electronic technology as a device for specific use in the carbonization process.

However, raw bamboo is a poor heat conductor. For this reason it is not simple to fully and smoothly control the carbonization process with an electronic automatic heat control device. Controlling the carbonization temperature using such a device still requires considerable knowledge, which can only be learnt from experience.

The research experiments concerning the relationship between bamboo and carbonization are described as follows:

1.1 Bamboo Test Samples

Five species of sample bamboos were used.

Mosochiku	*(Phyllostachys pubescens Mazel ex Houzeau de Lehaie)*
Hachiku	*(P. nigra (Loddiges) Munro var. Henonis (Bean) Stapf)*
Keichiku	*(P. makino Hayata)*
Madake	*(P. bambusoid Sieb. et Zucc)*
Dulcis	*(P. dulcis McCiure)*

1.2 Preparation of Sample Bamboo and the Use of Pre air-oxidization

The preparation of the sample bamboo involved cutting the bamboo into small sample pieces at 3 cm long and 1 cm wide. Some of these samples were put aside and were not pre air-oxidized. The remaining sample pieces were then pre air-oxidized in a fan forced chamber at 200°C for 20 hours. After pre air-oxidization, some of these samples were frozen, then crushed, and re air-oxidized at the same temperature for the same duration of time.

Note: In experiments throughout this report, pre air-oxidization & re air-oxidization are always at 200°C in a fan forced chamber for 20 hours.

This method were chosen as the control, because although other methods were tried, such as vacuum drying, and Steam Explosion Process (SEP), the pre air-oxidization method showed the most outstanding results.

1.3 Differential Thermal Analysis

The Differential Thermal Analysis (DTA) in *Figure* 1, shows two separate charts with plotted lines. These charts plot two full carbonization processes, both using Hachiku bamboo samples. Chart (A) represents non-pre air-oxidized carbonization, and the lower chart (B) pre air-oxidized carbonization. When the two are compared, (B) shows four improvements.

1.3.1 The dehydration phase commenced earlier.

1.3.2 A reduction in necessary dehydration was shown.

1.3.3 A lower heat spectrum of 338K was used in sample (B), verses 343K in sample (A).

1.3.4 It is believed that because of the reduction in necessary dehydration, and the fact that a lower heat spectrum could be used, there was a reduction in the decomposition of the material to be carbonized.

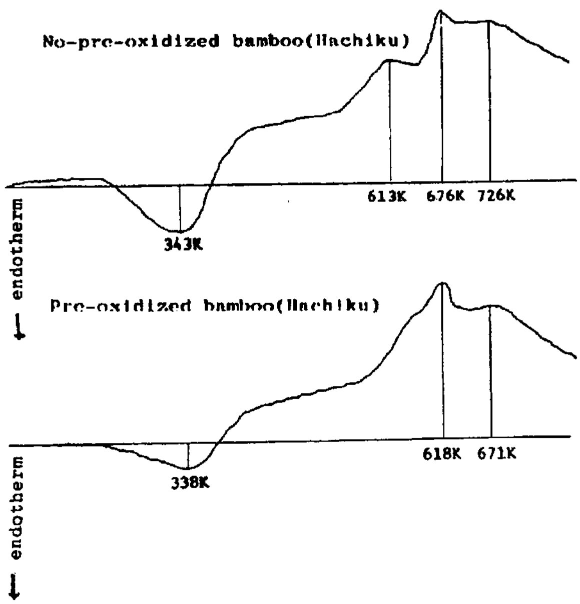


Figure 1 DTA Analysis of the bamboo (Hachiku) and the pre-oxidized bamboo

1.4 The Bamboo Carbon Yield

As shown in *Table 1*, all the test bamboo raw material was carbonized with Heat Treatment Temperature (HTT) at 973K. After this carbonization, the pre-air oxidized bamboo samples were then compared with the non pre air-oxidized samples.

The data showed that Mosochiku without pre-air oxidization gave a carbon yield of 25.3%. But, without crushing, and simply using pre-air oxidization, the Mosochiku increased its carbon yield to 40%. When Mosochiku was pre air-oxidized, frozen, crushed, then re air-oxidized, the yield increased to 44.8%. Thus a progressive increase is shown in carbon yield by the use of different versions of pre air-oxidization.

Table 1 also examines the remaining four species using a simplified version of the full pre air-oxidization process. Deleting the first pre air-oxidization process, the bamboo was simply crushed, and then pre-air oxidized. In the four remaining species this produced an average improvement in the carbon yield of almost 40%

Table 1 The Yield of the Bamboo Carbons for Heat Treatment at 973 K

Bamboo Samples	Yield of Carbons (%) #
Mosochiku	
*	25.3
#*	40
***	44.8
Hachiku	
**	45
Dulcis	
**	35.1
Keichiku	
**	40.6
Madake	
**	36.8

: % base on the air dried sample
* : no pre-oxidizing treatment
** : crushed and pre-oxidized 20 hr
***: pre-oxidized 20 hr and after crushed and oxidized 20 hr
#* : no-crushing, pre- oxidized 20 hr

As shown in DTA (see section 3), it is believed that pre-air oxidization causes earlier dehydration (polymerization-condensation, cleavage of functional group), and a reduction in decomposition of the material to be carbonized.

From this it could be considered that some atoms in the pre-air oxidized bamboo were decomposed by the chemical reaction, and that some of these decomposed atoms were vaporized. As a result, we see a shorter carbonization process, and an increase in the carbon yield.

1.5 Surface area of bamboo carbon

Table 2 shows several kinds of surface areas of bamboo carbons. There are five species of bamboo samples, using several versions of preparation before carbonization. The preparations used were:

- non pre air-oxidized
- pre air-oxidization
- pre air-oxidization, freezing, crushing, then re air-oxidization
- freezing, crushing, then pre air-oxidization

Using these combinations there are two carbonization temperatures of HTT, 1173K and 1273K.

Table 2 The Surface Areas of the Bamboo Carbons Corresponding to the HTTs and the Pre-treatments

Sample Pre-heat treatments	HTT (K)	BET Surface areas m^2/g
no pre-oxidized*1	1173	185
no pre-oxidized*1	1273	199
oxidizing, crush*2	1173	521
SEP-28 kg, 2min*3	1173	547
SEP-28 kg, 2min*3	1273	426
SEP-12 kg, 8min*3	1173	436
SEP-12 kg, 8min*3	1273	500
SEP-12 kg, 8min*3 after		
γ- ray irrad*4	1173	383
" *3*4	1273	374
Hachiku		
FC-OX*5	1173	582
FC-OX*5	1273	625
γ- ray irrad*4, FC-OX*5	1273	459
Bambusa Vulgaris		
FC-OX*5	1173	520
FC-OX*5	1273	536

*1: no pre-oxidized treatment
*2: pre-oxidized 20 hr and after freezing, crushed and oxidized 20 hr
*3: stream explosion process
*4: γ- ray irradiated; 1×10^8rad.
*5: the sample crushed after freezing and pre-oxidized

In this experiment it was found that the non pre-air-oxidized Mosochiku sample's surface area of carbon was $199m^2/g$ at 1273K; not a particularly large surface area. However, when a Mosochiku sample was simply pre-air-oxidized and carbonized at 1273K, the surface area of carbon increased 25% to $250m^2/g$.

But the full pre-air oxidization process showed a much more impressive result. When a Mosochiku sample was pre-air-oxidized, frozen, crushed, re air-oxidized, then carbonized at 1273K, the surface area increased dramatically to $599m^2/g$. This resulted in more than three times the surface area of carbon when compared with the non pre air-oxidized sample. A very impressive improvement.

The other four species, which were simply frozen, crushed, and then pre-air-oxidized also demonstrated a considerable surface area increase to an average of about $600m^2/g$ when carbonized at either 1173K or 1273K.

Thus is shown a definite and worthwhile increase in the surface area of carbon in all five species, by the use of some form of pre air-oxidization.

Summary

As previously outlined, five species of bamboo were used as samples in these experiments on the effects of non pre air oxidization verses different types of pre air-oxidization on the carbonization process. The analysis of these samples were examined in terms of improvements in DTA, carbon yield, and carbon surface area.

The DTA Hachiku analysis shows that the pre air-oxidized sample commenced its dehydration phase earlier, required less dehydration, and did not have to reach as high a temperature to achieve complete carbonization. Additionally, pre air-oxidization undertaken before carbonization increased the bamboo carbon yield considerably, and produced a significantly greater surface area of bamboo carbon.

Conclusion

From this it can now be seen that pre air-oxidization makes the bamboo carbonization process significantly more efficient, and is a procedure well worth researching.

It can also be seen that the five species discussed in this report have different characteristics, both in their raw, pre air-oxidized and carbonized state. For this reason each species will produce its optimum carbonized result, if pre air-oxidization and carbonization processes specific to that species are researched and used.

Unfortunately this report does not include any bamboo species from Thailand. Prior to commencing this report knowledge of Thai bamboo species was somewhat limited. Using Thai bamboo in experiments similar to those outlined in this report will greatly assist the bamboo charcoal project in Thailand.

But realistically, in order to do such experiments properly, a high performance electronically controlled kiln is necessary. With such a device, aspects such as temperature control and the speed of the increase of temperature are much more precisely metered. RFD does not have a kiln of such sophisticated specifications.

For this reason the installation of an electronically controlled kiln, similar to the Japanese Kankyo Techno Consul model, for experimentation purposes would be highly recommended. A Kankyo Techno Consul kiln has been used at Kyoto University in its demanding experiments for some years, and it has an excellent reputation for operational stability.

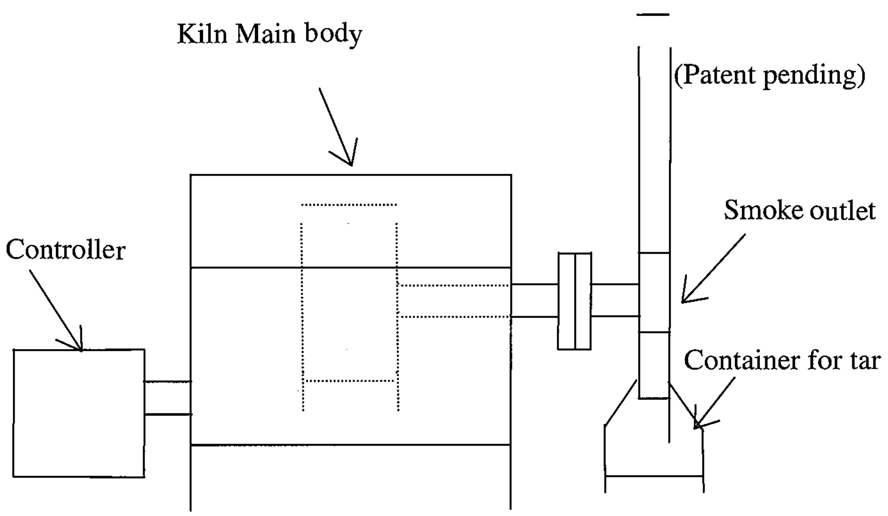
I am convinced that the purchase of a kiln of the same or similar specification is essential for any real success in researching the carbonization of bamboo in Thailand.

Electronically Controlled Charcoal Kiln

1) Description

In recent years, the merits and uses of charcoal have again enjoyed new popularity. To this end, we have developed this simply operated kiln to assist people who have little knowledge of carbonization and the charcoal making process. To make good charcoal you need the correct temperature. The kiln described here with its electronic control, can achieve and maintain the optimum carbonization temperature easily and without fuss. For these reasons, our electronically controlled charcoal kiln is perfect for use by schools, universities, research organizations and the hobbyist.

2) Basic Structure



3) Specification

• Kiln style	: Stainless steel charcoal kiln (Batch system)
• Heating system	: Electronically controlled, indirect electrical heating
• Electric power consumption	: 220V, 1kW
• Inner chamber capacity	: Diameter 100 mm×230 mm Height ,1.8 L
• Carbonization temperature	: maximum 1000°C
• External dimension	: Main inner chamber Diameter 400 mm×470 mm

Note: Collection container for Bamboo vinegar, and anti-smoking device are optional extras. Specially made custom size stainless steel kilns are available to suit your specific requirements.

4) Characteristics

a) A perfect control provides consistently good quality charcoal and bamboo charcoal.

b) The automatic electronic operation maintains the carbonization temperature and process time you require.

c) It can accommodate bamboo or wood of any type or shape; either chip or block.

d) It also has an absolute minimal exhaust of smoke pollution.

Produced by **KANKYO TECHNO CONSUL**

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Chapter II : The Current Methods of Carbonization for Bamboo Charcoal and Recovery of Bamboo Vinegar (Pyroligneous Liquor) and Charcoal Ash

Introduction

This chapter is divided into three parts. The first part (2.1) is an overview of current methods of carbonization for bamboo charcoal and the type of kiln used in Japan. The second part (2.2) explains the recovery method of vinegar. The third part (2.3) explains about the utilization of charcoal ash.

2.1 The Current Methods of Carbonization for Bamboo Charcoal

The ability to obtain high quality bamboo charcoal is based essentially on the combination of four items. These crucial items are: the type of bamboo, place of production, the burning process and the temperature control for carbonization. Putting the problems of bamboo characteristics aside for the moment, I would like to consider the combination of some kinds of burning processes and the highest temperatures for carbonization. The results of which are mentioned in *Table 3*.

2.2 Recovery of Bamboo Vinegar (Pyroligneous Liquor)

As the smoke from the process of making bamboo charcoal is cooled, condensation occurs to produce a type of liquid know as vinegar or pyroligneous liquor. For the purposes of this study I will refer to it simply as pyroligneous liquor. The ingredients of this liquid contain more than 200 chemical components, such as organic acids, alcohol, neutral materials, aldehyde, poly-phenol and alkaline. Depending on the range of the temperature, the quantity and type of ingredients change.

2.2.1 How to Recover Pyroligneous Liquor

Charcoal making is always accompanied by smoke. As smoke cools by outside air when passing through the chimney, condensation occurs to produce a type of liquid know as pyroligneous liquor. With the current increasing concern about environmental issues, the smoke from charcoal making could be called a pollutant. The pyroligneous liquor produced by the smoke from charcoal making, which could possibly be treated as villain in smoke circumstances, has many benefits. It can be used to stimulate the growth of vegetables and plants, and for the protection of plants from harmful bacilli and deodorization. In this sense, pyroligneous liquor pyroligneous liquor can be rightly called wonder water. The smoke produced by charcoal making contains organic matter which are products of the decomposition of the charcoal material. As organic matter is combustible, it can be returned to

Table 3 Carbonization methods and the type of kiln

Description of burning method			
Hard charcoal method (white charcoal)	Soft charcoal method (black charcoal)	Industrial high volume charcoal making methods	Simple charcoal making method, or Pit burning method
The type of kiln			
Mud kiln (Earthenware kiln)	Iron, or Fixed stainless steel kiln	Industrial Kiln, rotary kiln	Mobile carbonization kiln, or pit burning method
The range of the highest temperature (°C)			
800 -1000	500-700	400-500	400-500
Progress of carbonization, characteristics and nature of charcoal When carbonization times are compared, the soft charcoal method carbonizes faster than the hard charcoal method.			
Careful operation for about 3-7 days using a well-built mud kiln produces a high operating temperature resulting in a special occurrence called 'Nerashi'. To achieve Nerashi successfully it is crucial that the final part of the process is performed correctly. Do as follows... At the opening of the kiln, where the air enters, gently turn the charcoal lumps that have become red hot with a long iron bar. Then, little by little, guide the homogeneous charcoal to the entrance of the kiln and remove. It is then possible to use the powder (mixed ashes and soil) to smoother the flames of the red hot charcoal lumps. By doing this, the charcoal becomes hard, grey, and remains uniform.	After a few days at high operating temperature without 'Nerashi', keep the door closed and let cool. With this operation method the charcoal becomes black and is called 'black charcoal'. When compared with white charcoal, black charcoal is softer. As 'Nerashi' doesn't occur, the uniformity of the black charcoal is inferior. By combining the 'black charcoal method', and the 'white charcoal method', the carbonization time will be longer than using the straight 'black charcoal method'. By using the combined process 'Nerashi' can occur. Also, by using the 'combined process' and raising the highest temperature to 800°C harder bamboo charcoal can be produced.	A type of kiln, which usually processes crushed chips of bamboo. The chips are placed in a moving or tilted rotary kiln in a continuous process of carbonization. The main advantage of this kind of kiln is that it offers short carbonization times. It is therefore able to process large volume of bamboo. Also, when compared to a mud kiln, the uniformity of its output is more consistent. However, such kilns have several disadvantages. These kilns use advanced operational apparatus resulting in the kiln having a high cost. Because these kilns are not able to reach as high an operating temperature, the result is soft charcoal. The uses for such soft charcoal are limited.	To make a temporary or mobile carbonization kiln, you can use a steel drum or even an oil can. On the other hand pit burning can be achieved by simply digging a hole, placing the bamboo in a line, and covering with soil. In either case the operating temperature during carbonization will be low, resulting in soft charcoal. The resulting charcoal will also be lacking in uniformity. But anyone can make bamboo charcoal by this method. For this reason making bamboo charcoal has become popular. While often the charcoal is not completely burned and is soft, it is quite suitable for use on farms as a fertilizer.
Yield rate			
The yield rate is 10-12%.	The yield rate increases to 10-20%.	The yield rate is around 15-25%.	The yield rate depends on the type of kiln used, but the mobile carbonization fireplace yields a rate of 15%.

the carbonization kiln to be used as a heat source as in the case of a rotary kiln. Apart from exceptional circumstances such as the use of a special mechanized kiln, pyroligneous liquor is commonly produced as a byproduct of charcoal making.

In line with the recent social trend of efficiently using resources, there have been many attempts to recycle resources and to utilize hitherto unused resources. Plant resources, of which wood resources are the mainstay, are no exception and new applications of plant resources have been developed. As part of this trend, many plants are now used as the raw materials for charcoal making. Today, there are many divers of charcoal wood including: thinned wood, driftwood trapped by dams, sawdust and backboard dust produced by sawmills, windfall trees, dead trees, waste wood from demolished buildings, bamboo, straw and rice husks. Different charcoal woods require different carbonization kilns, but the principle of charcoal making i.e. baking charcoal wood by regulating the air flow, remains the same for all types of kiln. Similarly, the principle of recovering pyroligneous liquor has remained unchanged.

To recover pyroligneous liquor, the chimney is placed 20 – 30 cm above the smoke outlet of the charcoal kiln while a container at the lower end of the chimney is placed to collect the dripping condensed liquid. *Figure* 2 shows the pyroligneous liquor recovery system using a stainless steel pipe chimney. The pipe length is 7–10 meters to enhance the cooling effect. If it is difficult to prepare of such a length, a pipe of 2 – 3 meters can still recover pyroligneous liquor with a lower yield. As *Figure* 2 shows if a recovery system hood is placed at the base of the chimney, the efficiency of recovering pyroligneous liquor is improved. Some large–scale industrial charcoal kilns set up a water cooling system around the chimney to efficiency cool the smoke.

The key point is to separate the smoke outlet and the chimney between 20 – 30 cm. If the smoke outlet and chimney, which acts as cooling device, are directly connected, it has the effect of lengthening the chimney, which affects the airflow inside the kiln. This in turn has an adverse impact on the charcoal quality.

The stainless steel pipe can be substituted with bamboo. As the diameter of bamboo is smaller than that of the smoke outlet, it is necessary to use a clay pipe of which the diameter is 20-30 cm larger than that of the smoke outlet. It is placed above the smoke outlet. Several bamboo stems are then connected to this clay pipe. *Figure* 3 shows the pyroligneous liquor recovery system designed by Tsurumi, a teacher at the Kimitsus Agricultural and Forest College. This system uses a bent clay pipe and *Phyllostachys* *pubescens* (mosochiku). Two to three bamboo stems with the nodes removed are placed in the clay pipe to act as a substitute to the stainless steel pipe. In Southeast Asia bamboo can be used because it is an abundant natural product. In the case of Tsurumi's system (*Figure* 3), a bent clay pipe is installed at a distance of some 25 cm from the smoke outlet, as installation any closer draws the smoke too much which adversely affects the charcoal quality.

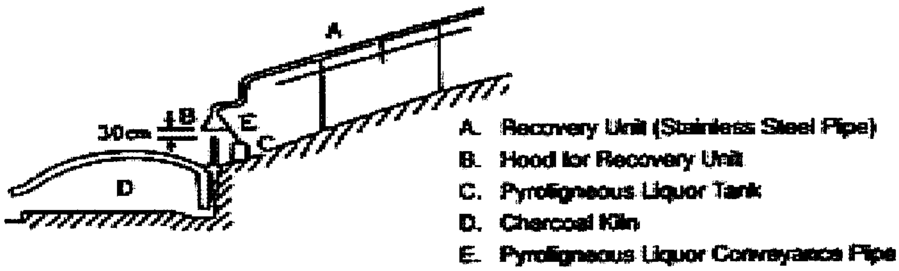

Figure 2 Kishimoto 's Pyroligneous Liquor Colleter

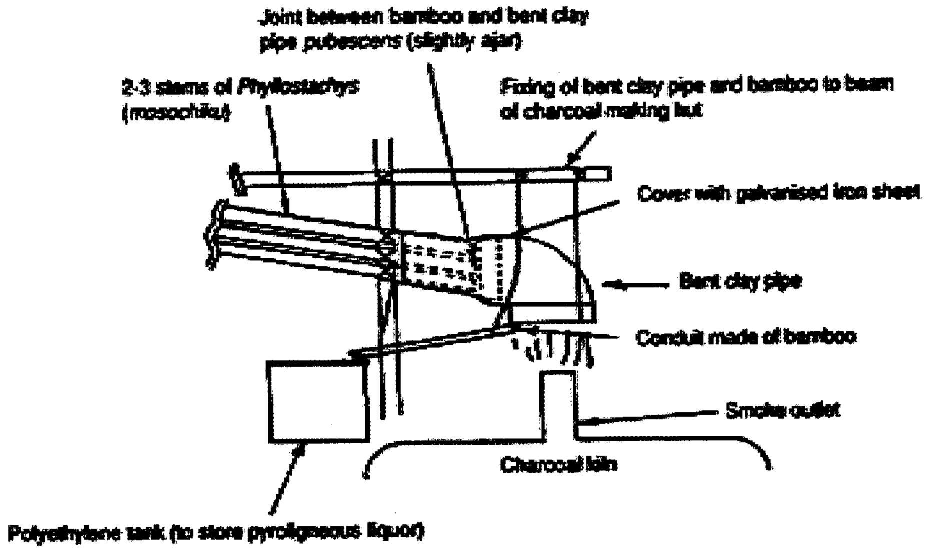

Figure 3 Tsurumi's Pyroligneous Liquor Recovery System Carbonization

2.2.2 Refining of Pyroligneous Liquor – How to Obtain Better Quality

Pyroligneous Liquor

Pyroligneous Liquor condenses into liquid form through the chimney, it then separates into three layers if is left to stand *(Figure 4)*. The bottom liquid which is black in color, has a thick consistency and is bamboo tar. The middle layer which is light yellow or reddish brown in color, has a good fluidity is raw pyroligneous liquor. The thin oil layer at the top is also bamboo tar. The bamboo tar which forms at the bottom layer is sometimes called precipitated tar as it precipitates when the pyroligneous liquor is kept still while the bamboo tar the top of is also called light oil. (2.3). The bamboo tar at the top is fairly thin and is sometimes difficult to see.

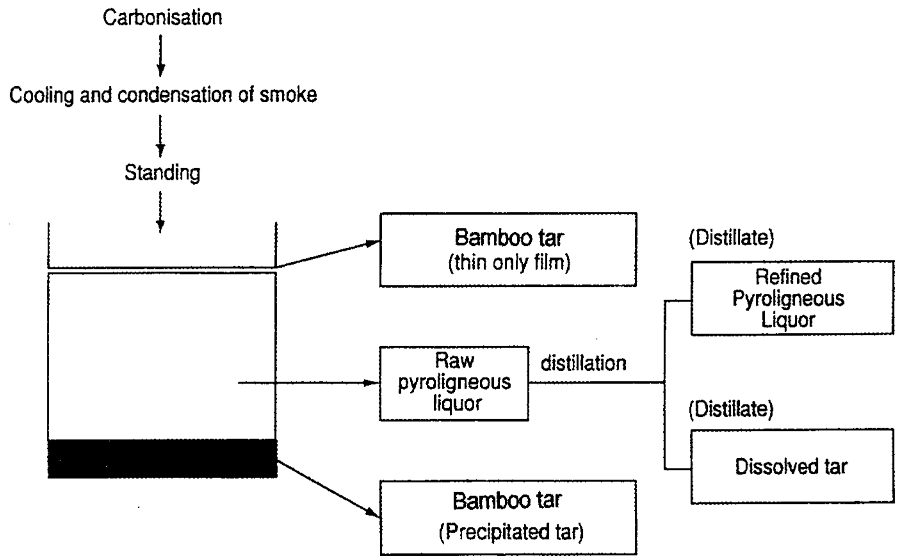

Figure 4 Pyroligneous Liquor and Bamboo tar

While raw pyroligneous liquor and precipitated tar separate easily for recognition into layers when left standing for half a day, the constituents of each layer are still dissolved in the other layers, albeit in small quantities.

The distillation of raw pyroligneous liquor, a yellow or reddish brown transparent liquid, is called refined pyroligneous liquor. The consistent residual of the distillation process is bamboo tar, which is dissolved raw pyroligneous liquor. This tar is called dissolved tar to distinguish it from the earlier mentioned precipitated tar.

Fresh pyroligneous liquor becomes opaque in time as a suspended polymer, while black tar sticks to the container wall. In fact, the original pyroligneous liquor has as many as 200 constituents, some of which are chemical compounds liable to polymerization or oxidation. These constituents, which are prone to such complex reactions as oxidation and polymerization, become suspended matter which stain the container wall. These constituents can impede plant growth if present in pyroligneous liquor for plant food application. It is, therefore necessary to refine raw pyroligneous liquor (*Figure* 5).

- Standing method
- Filtering method
- Distillation method
  - Normal pressure distillation method
  - Reduced pressure distillation method
- Dividing method

Figure 5 Refining Method of Raw Pyroligneous Liquor

<u>Refining Raw Pyroligneous Liquor has four Methods:</u>

1) Standing Method

There are several methods of refining pyroligneous liquor. The simplest and most highly efficient method is to keep pyroligneous liquor standing in a container. For this method, an acid-resistance container with an enameled finish or a polyethylene tank should be used in view of the strong acidity of pyroligneous liquor. When left standing, the unstable particles will adhere to the inner wall of the container. The thin oily film on the surface of the liquid must be discarded as well as the suspended precipitated matter must be filtered in order to produce transparent pyroligneous liquor. The appearance of suspended matter in transparent pyroligneous liquor after further standing means that unstable constituents remain which requires further filtering. When the standing and filtering process is repeated several times, stable, transparent pyroligneous liquor is obtained. Some 6-12 months of standing is required to obtain such stable pyroligneous liquor. While the standing method requires a long time, it is easy and inexpensive and a good result is assured.

2) Filtering Method

For this method, filter paper or a filter is used to remove the precipitated as well as suspended matter. Although transparent pyroligneous liquor is obtained immediately after filtering, the filtering of freshly recovered pyroligneous liquor cannot fully remove unwanted constituents which later cause the appearance of suspended matters or the staining of the container wall. The most efficient method is to combine the filtering method with the standing method to refine raw pyroligneous liquor. In the filtering process, the oil and suspended matters in pyroligneous liquor gradually clog the filter paper or filter, lengthening the filter time. In order to prevent this, a frequent change of the filter paper or filter is necessary.

Another way of filtering pyroligneous liquor is to fill a cylinder with activated charcoal, powdered charcoal, silica gel or diatom earth and to pour pyroligneous liquor over the top of it. It is also possible to mix activated charcoal or powdered charcoal with pyroligneous liquor at a weight of 10-30% for subsequent filtering after the agitation and standing of the mixture.

3) Distillation Method

The distillation method uses different boiling points of the constituent to refine pyroligneous liquor. In general there are two distillation methods: the normal pressure distillation method under atmospheric pressure, and the reduced pressure distillation method. In both cases, the evaporated compounds produced by heating pyroligneous liquor are separated and a special distillation system is required. Separation by means of distillation is very effective if the boiling point of the compounds are quite different. In the case of pyroligneous liquor, which has a water content as high as 80% -90% and an organic matter, content of 10% makes for a slim differential in boiling points. The separation and refining by means of distillation are technically demanding. This method is, however, quite effective to remove harmful substances with the removal of unwanted polymers. It is more practical to use the distillation method after using the standing method to remove precipitated as well as suspended matter. Only a small portion of the refined pyroligneous liquor sold in the market is actually distilled pyroligneous liquor.

While the normal pressure distillation method is relatively easy to conduct, the reduced pressure distillation method requires special skill to determine the right levels of reduced pressure and temperature. However, the reduced pressure means a low vapor pressure of the constituents, making it possible to use a lower temperature for distillation than the temperature required by the normal pressure distillation method. Because of this advantage, the reduced pressure distillation method is suitable to separate and remove unstable constituents.

4) Dividing Method

This method uses alkaline or acid reagents to divide pyroligneous liquor into acid groups, neutral groups, phenol groups and base groups. As the processes involved are very complicated, it is only used for research on the constituents of pyroligneous liquor refined by one of the three methods described previously in a mixture of acid phenol and neutral constituents. The dividing method has the advantage of further separating these constituents.

2.2.3 Judgment on Quality of Pyroligneous Liquor

The quality of pyroligneous liquor varies depending on the type of charcoal kiln, type of bamboo charcoal and carbonization temperature. Even if the liquor is transparent and does not stain the container, it is not necessarily high quality pyroligneous liquor. The quality cannot be judged visually. How then is it possible to judge the quality of pyroligneous liquor with as many as 200 constituents? Actually, there are many simple indicators such as the following:

1) pH Paper

This indicates the level of acidity. While a pH meter is required for a very accurate measurement, easy to use and inexpensive pH test paper which is widely available is sufficient to judge the quality of pyroligneous liquor. In general, pyroligneous liquor has a pH value of around 3.0. Some Bamboo pyroligneous liquors, however, have a value of less than 2.0 or higher than 5.0 because of the specific charcoal wood and/or carbonization method used. Pyroligneous liquors with a much lower or higher pH value than usual are required to be diluted in order to be suitable for certain applications.

2) Specific Gravity

The standard specific gravity of pyroligneous liquor is around 1.010 – 1.050 when measured using a standard hydrometer or heavy Baume's hydrometer at a liquid temperature of 15°C. If the measured value exceeds this range, it signifies the presence of dissolved tar and inorganic matter which is detrimental to plant growth. This will require the refining of the liquor.

3) Color

The color of pyroligneous liquor can be judged visually to determine the quality. Goodquality pyroligneous liquor has a pale yellow, bright brown or reddish brown color. Poor quality pyroligneous liquor usually has a dark color. Advanced polymerization results in a dark black color.

4) Odor

Good quality of pyroligneous liquor has the peculiar smoky odor of pyroligneous liquor. A high level of acidity produces a strong irritating odor, indicating the need for further refining.

5) Dissolved Tar Content

When pyroligneous liquor is placed on an evaporating dish and heated by a burner, a black residue is obtained. The proportion of this residue to the original pyroligneous liquor by weight is the dissolved tar content. As this dissolved tar contains pitch and other impurities, a lower dissolved tar content indicates a better quality pyroligneous liquor. The normal content is not more than 3%.

6) IgnitionResidue

As in the case of measuring the dissolved tar content, pyroligneous liquor is placed in an evaporating dish and then heated. Here, the black residue in the dish is further heated until it ignites.

What is left over, which is reddish brown or black brown solid matter, is called the ignition residue. This ignition residue contains incombustible inorganic matters. The proportion of the ignition residue to the original pyroligneous liquor by weight is normally not more than 0.2% in the case of good quality pyroligneous liquor.

7) Transparency

Transparency is judged visually. Good quality pyroligneous liquor is transparent with no suspended matter. If the liquid is not clear, it must be filtered.

Pyroligneous liquor should be stored in cool place, avoiding direct sunlight. It must be remembered that an iron container should not be used in order to prevent any chemical reaction between the iron and the strongly acidic pyroligneous liquor from making holes in the container.

2.3 Utilization of Ash

The technical analysis of charcoal indicates an ash content of 1–3% as shown in *Table 4.* Although the actual ash content varies depending on the specific type of charcoal wood and carbonization temperature.

2.3.1 Charcoal Ash

This ash content remains even after the complete combustion of charcoal. Water, volatile components, and fixed carbon turn into gases during charcoal combustion and therefore, do not constitute ash.

The constituents of charcoal ash for example, with the *nara* (Japanese oak) charcoal is calcium at 40%, and potassium and sodium jointly account for slightly more than 16%.

In addition, there are also such microelements as phosphorous, iron, and manganese. As most of these ash constituents easily dissolved in water, the application of ash to soil has the immediate effect of supplying minerals to the soil.

Table 4 Technical Analysis of Charcoal

Type of Charcoal	Technical Analysis Results Unit: %			
	Moisture	Ash	Volatile	Fixed Carbon
Japanese oak (Hard Charcoal)	9.02	1.32	5.60	84.06
Evergreen oak (Hard Charcoal)	6.60	1.80	5.29	86.31
Mosochiku (Hard Charcoal)	6.20	2.20	9.30	82.30
Madake (Hard Charcoal)	8.50	3.10	9.90	78.50

2.3.2 Useful Applications of Ash

Fertilizer and Soil Improvement

Ash has been used by farming households since olden days as a home-made potassium fertilizer. It can be mixed with compost used as a principal or supplementary fertilizer. Seeds are sometimes dipped in ash before sowing. The oldest type of ash fertilizer was made from grass or wood and ash made from straw and rice bran was later used. Wood ash made from broadleaf trees has a higher potassium content than ash made from trees with needles.

Wood ash burned at a high temperature of 700°C or higher is alkaline in pH at 8.5-9.5 and is very useful to neutralize acid soil.

The application of an appropriate amount of ash can neutralize farmlands suffering from problems originating from repeated cultivation or acid due to the excessive use of agar. Chemical fertilizers and can also supply microelements to restore the fertility of the soil.

Table 5 Fertilizing Constituents of Ash

Constituent	Ash Type Unit: %		
	Wood Ash	Straw Ash	Bamboo Ash
Potassium	11.7	4.5	8.60
Phosphoric acid	3.9	2.1	2.47
Lime	2.3	2.3	0.95

Chapter III : Benefits of Bamboo Charcoal

3.1 Carbonization Methods to make Bamboo Charcoal

As in the case of wood charcoal, bamboo charcoal is made by not only charcoal kilns but by also state of the art carbonization furnaces. The bamboo species used include *mosochiku (Phyllostachys pubescens)* , *madake (Phyllostachys bambusoides)*, *hachiku (Pyllostachys nigra)* and *nemagaridake (Sasa kurilensis)*.

Thin bamboo is made into round charcoal while thick bamboo is vertically cut into two or four pieces to make flat charcoal. To make charcoal from different bamboos the same kiln may be used, but different temperatures are required for different types of charcoal for different purposes. The different temperatures are low at 400°C, medium at 600°C - 700°C and high from 1,000°C or higher.

The process of making bamboo charcoal is by the circulation of the bamboo inside the kiln, which slowly dries the bamboo's water content over a period of 3 – 4 days. This is accomplished by gradually increasing the kiln temperature thus carbonizing the bamboo in 40 – 50 hours. Refining work takes 4 – 5 hours.

3.2 Properties of Bamboo Charcoal

Compared to wood charcoal, bamboo charcoal has advantageous characteristics such as easy carbonization, low tar content, higher level of hardness due to its relative high silica acid content and better filterability. As the heat decomposition process initially produces many acid constituents, including formic acid, a carbonating kiln must use stainless steel or other acid-resistant materials.

Bamboo charcoal also enjoys a high level of porosity and has a large surface area of some 200–300 m^2 per gram. The adsorption capacity of bamboo charcoal carbonized at a high temperature of 1,000°C is approximately ten times that of Bincho charcoal. Because of this excellent adsorption performance, bamboo charcoal is used for deodorants and moisture adsorbents. It is also used for bedding, soil improvement and other purposes.

Chapter IV : Application of Bamboo Charcoal and Pyroligneous Liquor

Introduction

Bamboo charcoal has a wide variety of applications, for example, water purification, rice cooking, soil improvement, humidity control etc. The level of charcoal products is also different depending upon the manufacturer or the individual that produced them. There are not only good charcoal products but also bad ones which are sold at market.

4.1 Application and Uses for Bamboo Charcoal

Herein is a review of the applications for bamboo charcoal in relation to the experimental data from our study. The results of which are shown on *Table 6.*

Table 6 Application and Uses for Bamboo Charcoal

No	Subject	Description
1	Fuel	Bamboo charcoal can be used as a BBQ fuel. It is easy to light and has strong heating properties. However, it only burns for a limited time due to the thinness of the material. If a longer cooking time is required, it is therefore better to use bamboo charcoal together with wood charcoal.
2	Drinking Water	If hard bamboo charcoal is added to tap water, the charcoal decomposes the chlorine and any other added chemicals in the water. Also, minerals contained in the charcoal dissolve in the water, helping to improve its taste. If hard bamboo charcoal is being used for this purpose, it is wise to wash the charcoal with water before using.
3.	Rice Cooking	Placing bamboo charcoal with rice while cooking will improves its taste, enhance its aroma, and prevent the rice from becoming yellow. The bamboo charcoal can be re-used about five times for this purpose. These findings were researched by Dr. Minamide, Department of Human Environment, Kyoto Prefecture University, Kyoto, Japan.
4.	Bathing	If bamboo charcoal is housed in a netting bag and placed in the bath, it has a warming effect on the body, an effect that continues well after bathing. If the bamboo charcoal is then drained and dried in the sun, it can be used repeatedly for this purpose. When the charcoal is used in this way, it may shed a small amount of charcoal powder in the bath, but this is harmless. This was researched by Dr. Hosokawa, Department of Living Science, Kyoto Prefecture University, Kyoto, Japan.

No	Subject	Description
5.	Soil Improvemen t	Bamboo charcoal can be used as a replacement for chemical fertilizers and agricultural chemicals. In practice, this is simply a matter of plowing fragmented pieces of bamboo charcoal into the soil. This will increase the yield and the quality of crops.
7.	Building Humidity Control	Placing bamboo charcoal under the floor, or in the wall of a building, helps control surplus moisture. This is effective when it is humid, and/or when rainfall is high. Bamboo charcoal has the opposite effect during the dry season. It will restore moisture absorption and act as an insulator to keep the building warm in winter. However, bamboo charcoal should be used with caution for this purpose. If the charcoal is placed in an overly dry environment where there are high atmospheric temperatures, there is risk of natural ignition.
8.	Preservation & freshness of vegetables	When stored in a refrigerator or storehouse, fresh vegetables and fruits produce ethylene gas. Bamboo charcoal absorbs this gas, thus helping maintain the freshness of the fruits and vegetables. However, bamboo charcoal loses its ability to absorb ethylene gas if the surface of the charcoal becomes damp. To maintain its effectiveness in this purpose, the charcoal must therefore be kept dry. These findings were researched by Dr.Hosokawa, Department of Living Science, Kyoto Prefecture University, Kyoto, Japan.
9.	Deodorization	Bamboo charcoal can absorb and breakdown undesirable odors. However, it should be stated that if working with rubbish or garbage of any kind, better results would be found by instead using bamboo vinegar, (*bamboo pyroligneous liquor)*. This was researched by Dr. Minamide, Department of Human Environment, Kyoto Prefecture University, Kyoto, Japan.
10.	Bedding	Placing bamboo charcoal inside a pillow or mattress increases comfort to help provide a good nights sleep. This is because when charcoal is used in this way, it improves ventilation and helps to keep the bed warm. (Some people believe that bamboo charcoal discharges a kind of electromagnetic wave that is useful. However, the details concerning this are not clear.)

4.2 Charcoal as Electromagnetic wave Shielding Material *

Any organic matter, regardless of its original state being a gas, liquid or solid, is to said to become a large molecule with a condensed polycyclic polymer aromatic structure with the gradual loss of heteroatoms when it is heated in a range of between 500°C and 1000°C in an oxygen free condition. Once the temperature exceeds, 1,000°C the crystal growth further progresses. The organic matter becomes graphite when the temperature exceeds 1,800°C - 2,000°C. As wood is a composite material of which the main constituents are cellulose, hemicelluloses and lignin, the structural changes during the process of temperature increase are believed to be similar to those described above. However, the physical properties of solid charcoal in the temperature range of between 300°C and 1,500°C, the so called charcoal making temperature range, particularly between 700°C and 1,000°C, are largely unknown. This is because of the difficulty of conducting electronic research on the material and in turn due to the unclear crystalline of charcoal. In contrast, the physical and chemical properties of wood during the processes of thermal decomposition are fairly well understood in the heat temperature range of below 300°C. Similarly, the detailed electronic properties have been established for the temperature range of more than 1,800°C based on research from graphite and carbon materials. As described earlier, however, the physical properties of charcoal in the charcoal making temperature range have not yet been sufficiently determined. The only facts established so far are that the electrical resistively declines in accordance with a rising temperature. Charcoal's properties change according to temperature: starting as a non-conductor at normal temperature up to 300°C, a semi-conductor at 300°C - 800°C, and a conductor at 800°C or higher. It is known that there are a large number of unpaired electrons which exist in charcoal around 700°C as shown in *Figure* 5.

Given the present situation where highly conductive materials are used as electromagnetic wave shielding materials, it is highly feasible that more charcoal in the future will be used as an electromagnetic shielding material. Its splendid features as a carbon material being carbonated at a heating temperature of 800°C make it an obvious choice. In fact, various excellent electromagnetic wave shielding materials have already been manufactured for practical use.

Figure 5 shows how the electromagnetic wave shielding effect of charcoal changes with a different heating temperature of sugi wood.

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* : "Charcoal as Electromagnetic Wave Shielding Materials", Shigehisa Ishihara, Charcoal Handbook.

According to this *Figure*, a positive effect above the required standard (30dB or higher) is only achieved when the heating temperature exceeds 800°C at which the charcoal begins to obtain electric conductivity. When the heating temperature exceeds 1,000°C, the charcoal has a better electromagnetic wave shielding performance than that of such standard materials as sheet iron and aluminum sheeting. The materials shown in *Figure* 6 are 1-2 mm thick sheets manufactured using special technologies and the electromagnetic wave shielding performance is similar to that of a sheet or film.

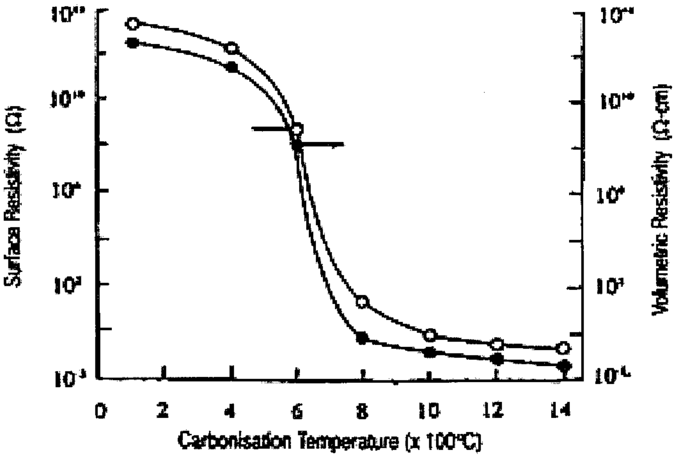

Figure 5 Relationship Between Carbonization Temperature of Sugi and Electrical Resistively of Sugi Charcoal

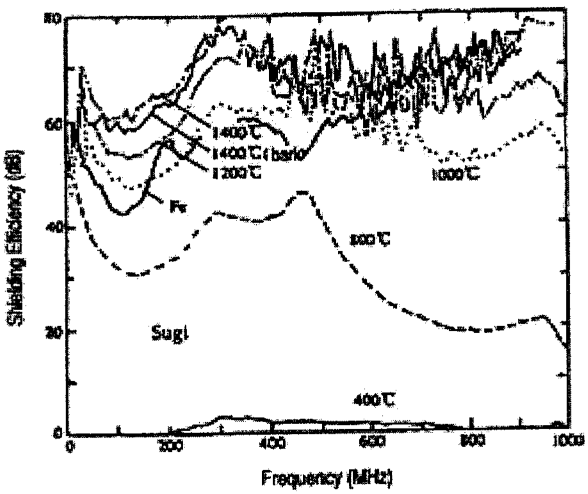

Figure 6 Impact of Carbonization Temperature on Electromagnetic Wave Shielding Performance of Sugi Charcoal (Facilitates a standard iron sheet with a thickness of 1.65 mm.)

Figure 6 shows the measurement results of the electromagnetic wave shielding performance of sheets made from ubamegashi (*Quercus phylliraeoides*) and cellulose charcoal, prepared with charcoal made from phenol formaldehyde resin and all carbonized at 1,200°C. This is also the same temperature for charcoal made from sugi sapwood referred to in *Figure* 6, along with a sheet of graphite molded with phenol formaldehyde resin.

Both the wood charcoal and cellulose charcoal have the same quantity of phenol formaldehyde resin as the graphite sheet. This shows that the wood charcoal is an excellent electromagnetic wave shielding material. While it is found to be difficult to shield a magnetic field with these materials, the shielding of a magnetic field is made possible by heating them at a temperature of 1,800°C to 2,000°C or by compound burning with other materials. These are temperatures higher than the charcoal making temperature range.

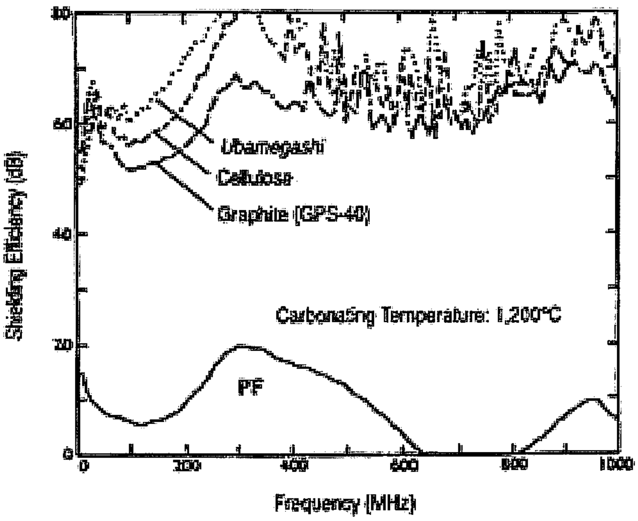

Figure 7 Comparison of Electromagnetic Wave Shielding Performance of Various Materials Carbonated at 1,200°C

Figure 7 shows the different shielding performance of charcoal with various carbonization temperatures along side other familiar materials. In short, charcoal which is carbonated at a high temperature can be used as a mounding material or it can achieve a shielding performance which is comparable to or higher than metal sheeting. In addition, the low specific gravity of charcoal makes it a very light electromagnetic wave shielding material beyond the reach of metal materials or polymeric materials. As electromagnetic wave shielding materials using charcoal offers: fire resistance, heat resistance, oxidation resistance, chemical stability, anti-degradation, high dimensional stability and biological affinity. At the same time charcoal's applications are not confined to the bodies of electronic equipment but also include building materials and components for automobiles, trains, spacecraft, airplanes and ships.

At present, the development of electromagnetic wave shielding materials using charcoal has reached the stage where charcoal with a volumetric resistively of 10^{-3}–10^{-4} Ω cm and an electromagnetic wave shielding efficiency exceeding 100 dB can be prepared using the new carbonization method at 1,000°C. The author's group developed it and efforts are currently in progress to develop its practical application as an electromagnetic wave shielding component for precision micro-equipment.

What is required of charcoal as an advanced material today is clarification of its electronic properties and the development of charcoal making technologies and systems to accurately control the carbonization temperature,. so that the various features of charcoal can fulfill useful functions.

In this report, the author did not discuss bamboo charcoal. But, the author did state that in the case of bamboo charcoal, it has also shown electromagnetic shielding properties similar to that of wood charcoal. The reference is "Charcoal Revolution" edited by Ginji Sugiura, and authored by Shigehisa Ishihara, p.140 Makino Shytupan 1992.

There are many textbooks and documents on electromagnetic waves and electromagnetic wave shielding.

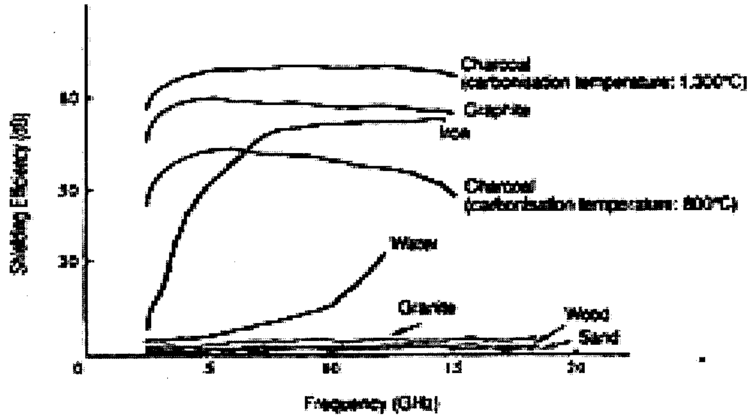

Figure 8 Electromagnetic Wave Performances of Various Materials

Two excellent books which are scientifically sound and easy to read are "What are Electromagnetic Waves? Let Us See Invisible Waves" by Naohisa Goto, Kodansha, 1987 and "Electromagnetic Disturbance" by Shin Hasegawa, et. al. , Sangyo Tosho, 1991.

4.3 Bamboo Carbonized Formed Board **

For Japanese wooden buildings, floors, wood materials and soil foundations are usually chemically treated for anti-termite. The chemical for soil treatment contains any VOC (Volatile Chemical Substance), so it should be sprayed about every five years. This may be a cause of the new disease called "sick house syndrome". Now wooden building bases are constructed using a procedure called "continuous footing," which has ventilation holes at the bases, and the bases are covered with concrete. Condition footing is earthquake tolerant but achieves less airflow, thus increasing the humidity under floor. For the upper portion of the building, new chemical materials are used in order to air proof by a thermal protection system. These factors might be a compound cause of chemical over-sensitivity syndrome.

To improve such poor under floor conditions, experiments have been conducted in five cities in Japan. In these experiments wood charcoal pieces were buried under the floors, and the humidity was measured. The result showed that when charcoal pieces were used the humidity dropped from 90 – 100% in a rainy season to 75 – 80%. To improve the upper portion of the building, a bamboo carbonized formed board has been developed. At the development stage, cellcolase (R), which is a binder of high polymer systems from natural fiber, was one of high quality bamboo charcoal carbonized formed board materials. For the binding materials, recycled paper, waste leather, and scrap wood were used. The bamboo carbonized formed board should satisfy the following conditions; (1) it can be re-cycled, (2) it gives no damage to the environment when it is discarded as a building material. It is a material which can offer a healthy environment for home life. Its architectural qualities are numerous: flame resistant, soundproof, heat insulation, radio wave blocking, humidity control, and chemical adsorption. Good design and easy installation are needed factors for construction materials, both of which it posses. The carbonization performance should be maintained even if the bamboo charcoal is produced as flat board. For example, when a bamboo board sucks up water, the percentage of adsorption is about 158%, thickness change is 1.8%, and elongation change is 1%. These figures are similar to those in the radial and longitudinal direction of fiber when the raw material bamboo is measured. After drying the board

** : "A New Housing Materials – Bamboo Carbonized Formed Board", Shinsuke Fujita Bamboo Voice No.1 p2. 2000. Japan.

several times, these figures return to its original measurements. This is because most of the water is contained in the gap of bamboo charcoals or in cellcolase (R) which is a binder of the board. The physical adsorption by cellcolase (R) is miniscule, only 1-2% of expansion and contraction.

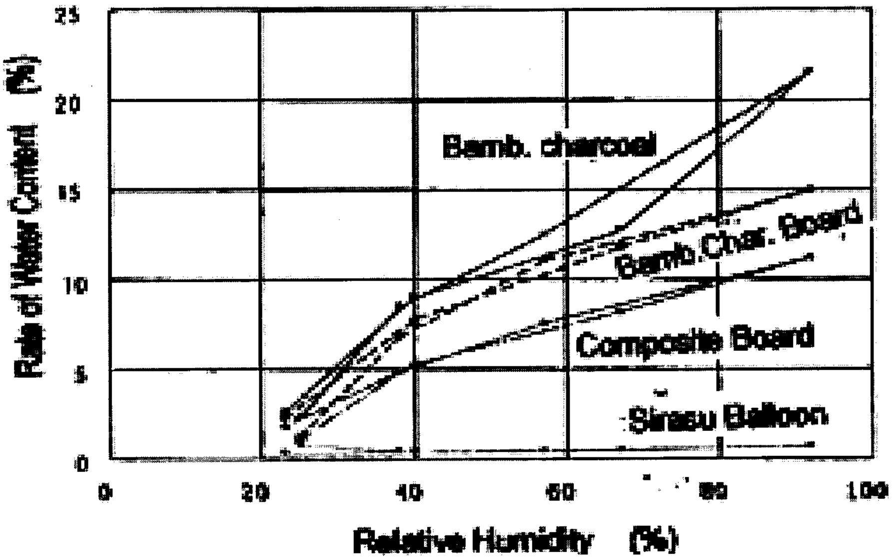

Figure 9 Absorbency of Carbonized Formed Board

As showed in *Figure* 9, comparing bamboo charcoal materials with bamboo carbonized formed boards for equilibrium percentage of water content, bamboo charcoals have about 23% and a bamboo carbonized formed board have 15% at 90% of relative humidity. If they are measured at 70% or less relative humidity, no big difference is found in the equilibrium percentage of water content. They have similar moisture adsorption desorption characteristics, and can absorb under desorption repeatedly. It is found that the bamboo carbonized formed board also absorbed formaldehyde.

The flexural strength of a bamboo carbonized formed board is 1-1.5Mpa, the stiffness coefficient is 183.7Mpa, and the peel strength is 228Mpa. These values are similar to those of insulation board value. Its heat insulation qualities are inferior to those materials from oil. The noise absorption is the same as those of porous materials.

In conclusion, the board can be used for wrapping, transportation carts, agriculture, industrial and bedding materials.

4.4 Application of Bamboo Pyroligneous Liquor/Bamboo Vinegar (Bamboo pyroligneous liquor as a Bactericide and Deodorizer) ***

Bamboo pyroligneous liquor, commonly derived from Moso-chiku, is usually dark in color. It is similar to the liquid obtained when the smoke from wood charcoal kiln is condensed (wood pyroligneous liquor).

Pyroligneous liquor from bamboo charcoal making is still a new process and the product is unstable. It is currently being used mainly as a repellent for animals and as a growth enhancer in agriculture. It is believed that there could be more effective uses for this substance. It has been found that by stabilizing the temperature of the smoke from the charcoal kiln, and cooling it through contact with cold water, a high quality, light brown colored bamboo pyroligneous liquor can be derived. After refining, the liquid becomes nearly transparent and odorless. To demonstrate the deodorizing properties of bamboo pyroligneous liquor, a room deodorizer was developed and tested in a woman's public restroom in the Oita train station. The product is still being used in its third year, and plans call for its use in other stations as well.

Unfortunately, just as the market for bamboo pyroligneous liquor was growing, production of bamboo charcoal was stopped due to lack of sales. Without the production of bamboo charcoal, there could be no bamboo pyroligneous liquor since it is a by product of bamboo charcoal production. For this reason, an experiment plant to produce bamboo pyroligneous liquor from Madake bamboo, abundant in Oita prefecture, was completed in May 1997. The plant was designed to control temperature through sensors, using only the center portion of 3-5 year old sun dried madake stems. With this process a liquid with high bactericide properties can be obtained.

During the normal production of bamboo pyroligneous liquor, remnants of tar, methanol and formaldehyde remain in the liquid. For this reason it cannot be used as a food additive. To remove these toxic substances, an organic solvent extraction method for small amounts can be used.

Bamboo pyroligneous liquor consist of more than 95% water and contains more than twenty traces of organic materials including vinegar acid, acetone and furfural. A high quality bamboo pyroligneous liquor free from toxic substances would be useful for food sanitation. It is a powerful deodorizer and useful as a preservative and a bactericide. It could be used as

***: "Bamboo pyroligneous liquor as Bactericide and Deodorizer", Kenji Uchiyama Bamboo Voice No.4 p10. 1998. Japan.

a spray or in diluted water to kill even the dangerous O157 strain of the E.coli bacteria. Testing by the Japan Food Analysis Center shows that within 1 to 3 hours coli. Salmonella and Cocas bacteria can be killed.Used in food processing, it would act as a preservative. This is because it has a naturally strong acidic water make-up without chemical processing. It is being used more and more in food processing plants and food production centers.

Some of the new uses of bamboo pyroligneous liquor can be as a food additive or as an ingredient in medicines. Food additives are used for 2 main reasons: to improve flavor and to prevent spoilage. Bamboo pyroligneous liquor also can be used to fight skin infections due to scratching of infected areas of topic dermatitis. It is possible that the natural ploy-phenols and cresol contained in bamboo pyroligneous liquor improves this condition. It also can be used as a natural antibiotic.

Chapter V : Making Bamboo Charcoal and the Kiln

Introduction

Chapter 2.1 explained an overview of the current methods of carbonization of bamboo charcoal and the types of kilns used in Japan. This chapter will describe more about the kilns used specifically for making bamboo charcoal. It will include the advantages and disadvantages of each kiln, and the calculations of both the economical efficiency of the kilns and quality standards of bamboo charcoal.

5.1 Bamboo Material

The bamboo used for making bamboo charcoal is usually more than three years old and of a uniform species. After harvesting the bamboo, it is dried naturally for a couple of months. Then the dried bamboo is cut into suitable lengths, generally 80-120 cm. It is then cut lengthways into four quarter pieces or into six pieces. Next, the cut bamboo is placed into a dryer (or kiln, if a kiln is used as a dryer), and dried for 6-10 hours at 180-200° C. The moisture ratio is controlled at 15-20%.

5.2 The Charcoal Kiln and Carbonization Method

Continuing from *Chapter 2 (2.1 Table 3)*, I will explain the types of kilns, such as the mud kiln (an earthenware kiln), the fixed iron kiln and the industrial kiln. Also here, the burning methods will be explained, such as the hard charcoal (white charcoal) method, the soft charcoal (black charcoal) method as well as the industrial charcoal method.

5.2.1 Mud Kiln (an earthenware kiln)

The main advantage of the mud kiln is that it is economical to build, providing that suitable soil for building the mud kiln's walls is available near the site of the kiln. This reduces the material costs. Additionally, in a mountain village, there is a chance that a local person may have experience of charcoal making, and their advice may be used to build a new mud kiln. This is often why a mud kiln is chosen. However, building a mud kiln is not easy. It must have flat surfaces, and the structure of the walls must be sufficient for maintaining a high temperature, along with a strong roof built for heat resistance.

The hard charcoal method, producing one of the typical charcoals called 'Bin-cho-tan', usually utilizes a mud kiln. The material used for this type of charcoal is oak tree, which is hard and solid.

The hard charcoal method involves the special process of 'operating reforming' or 'Nerashi' during the final stage of carbonization in the kiln.

This special process can produce bamboo charcoal of a higher and more even quality. On the other hand, the use of the 'operating reforming' or 'Nerashi' process with the soft charcoal method makes the bamboo charcoal break in the kiln, because the bamboo material is not as thick and solid as the oak tree material.

So, the soft charcoal method of 'operating reforming' or 'Nerashi' is used during the final stage of carbonization, where the top of the kiln is opened a little, and the air valve at the bottom of the kiln is also opened to allow greater air flow. This operation produces the necessary rapid heat increase for uniform carbonization, and oxidizes the bamboo charcoal.

But there is a limit to what can be accomplished with the soft charcoal method of 'operating reforming' compared with the hard charcoal method of 'operating reforming'.

To acquire an even temperature range in the kiln using the hard charcoal method of 'operating reforming' is not easy. As a result, the soft charcoal method often produces bamboo charcoal of an uneven quality. Furthermore, the temperature inside the kiln during the process of bamboo carbonization reaches temperatures higher than that of wood combustion, so there is the possibility that the kiln may break or explode. For this reason, it is quite difficult to produce a high and even quality of bamboo charcoal with the mud kiln. Therefore, the iron kiln is favored most often to make bamboo charcoal.

5.2.2 Iron Kiln

As previously described in *Chapter 4 'Application and uses for the bamboo charcoal'*, which discusses making bamboo charcoal for new purposes other than fuel in Japan. Another reason why the iron kiln is becoming more popular is because it is easier to get the higher carbonization temperatures than with the mud kiln.

The iron kilns can be classified roughly into two types: one includes a dryer for the preparation of the bamboo material, and the other does not include a dryer. For the second type the bamboo material must be dried in another place and then brought to the kiln.

The iron kiln has several advantages compared with the mud kiln, and these are listed below.

1) The inside walls of the kiln are smooth and even.
2) It is easy to make an outside wall of suitable heat insulating material for maintaining high temperatures.
3) The top can be made strong for heat resistance.

(1-3 enables high and even quality bamboo charcoal to be produced, and the production is more stable with the iron kiln than with the mud kiln).

4) The walls do not need to be as thick as with the mud kiln. Thinner walls enable the kiln to cool down faster once the carbonization process has finished. Thus, the economical efficiency is increased due to the possible increase in the kiln's production runs per month.

5) The 'operating reforming' process is made easy by opening and shutting the air valve.

As mentioned previously, with the iron kiln, the soft charcoal method of 'operating reforming' is different from the hard charcoal method of 'operating reforming' during the final stage of carbonization.

This operation will produce the necessary rapid increase in burn heat inside the kiln required for uniform carbonization. The air valve control helps to produce a higher yield and also a higher and more consistent quality of bamboo charcoal.

5.2.2.1 The fixed stainless steel kiln

Also one of the latest kilns is the stainless steel which has a separate chamber. The separate chamber can make gas form from the fuel, and it is possible to put the high temperature gas into the main chamber to control the carbonization process.

a. One person using a crane can easily load the machine

Here, we will explain the basic specification of the Katayama Bamboo Charcoal Kiln. It has several advantages. Firstly, being of small and practical size one person using a crane can easily load the machine with raw bamboo material for the carbonization process. Secondly, with the kiln's effective design, the carbonization process only takes a short time.

b Physical specification of the bamboo charcoal kiln

The kiln consists of the main chamber (cylindrical in shape), the inner chamber (also cylindrical known as the rostyle), and the chimney. Its basic dimensions are:

Height	1600-mm (from the base to the top of the joint of the chimney)
Diameter	1000-mm
Inner chamber capacity	0.7 cubic meters (Approx. 300 kg)

The chamber is made from corrosion resistant stainless steel (type SUS 340) which is heat resistance to 850°C. Bamboo vinegar is also produced in the carbonization process. Because the bamboo vinegar is produced as a vapor, and passes through the chimney for collection, the chimney is also made from stainless steel. The wall thicknesses of the major components are...

Main chamber base	9 mm
Main body	6 mm
Inner chamber	3 mm
Chamber lid	6 mm

The base of the main chamber has a fire hole, an ash outlet, and four air control valves for the adjustment of the carbonizing process. On top ofthe main chamber there are also four side chimneys which have shutters. The top of the lid houses the main chimney which also has a shutter.

c Temperature Censor

The inner chamber has two holes for the temperature measurement censor. The temperature censor enables exact monitoring and control of the kiln temperature during the carbonization process.

d Kiln Insulation

The main chamber body and the lid are covered with heat insulating material. This is in order to retain heat and to control heat radiation outside the kiln, when the inner chamber gets hot during the carbonization process.

e Making charcoal

Here we will explain the process of making bamboo charcoal using the kiln. The description includes the selection of bamboo, loading the bamboo, bamboo ignition, control of carbonization, and removing the charcoal from the kiln. Notes on the kiln's production of bamboo vinegar are also to be found in this explanation below.

The stainless steel pipe can be substituted by bamboo of which the used has been removed. As the diameter of bamboo is smaller than that of the smoke outlet, it is necessary to use a clay pipe placed above thesmoke outlet, of which the diameter is larger than that of the smoke outlet by about 20 – 30 cm. Several bamboo stems are then connected to this clay pipe. *Figure* 3 shows the pyroligneous liquor recovery system designed by Tsurumi, a teacher at the Kimitsus Agricultural and Forest College. This system uses a bent clay pipe and *Phyllostachys pubescens* (mosochiku). Two to three stems with the nodes removed of this bamboo is placed in the clay pipe to act as a substitute to the stainless steel pipe. In Southeast Asia where bamboo is abundant, bamboo is the natural choice for this purpose. In the case of Tsurumi's system (*Figure* 3), a bent clay pipe is installed at a distance of some 25 cm from the smoke outlet as installation any closer draws the smoke too much which adversely affects the charcoal quality.

1. Selection and preparation of bamboo

We recommend the use of Mosochiku (*Phyllostachys pubescens* Mazel ex.Houzeau de Lehaie). The Mosochiku bamboo chosen for making charcoal should be at least three years old and dried for approximately a half year after harvesting. The harvested and dried bamboo is then cut into 1100-mm lengths, cut lengthways into four 'quarter' pieces, and then all joints are trimmed.

2. Loading of bamboo material: see *Figure* 10

Using a crane, remove the lid, then remove the inner chamber (rostyle) from the main body. Place the inner chamber where it is convenient to load the bamboo.

Pack the inner chamber with the prepared bamboo carefully to maximize use of space. Then using the crane, place the now loaded inner chamber back into the main body, and then place the lid back on.

3. Igniting the bamboo : see *Figure* 11

To ignite the bamboo, open the main body chimney's air control valve. Place burning old loose bamboo in through the fire hole. After 1.5 - 2 hours, the temperature censor will tell you that the inner chamber has reached about 100°C. This means that the bamboo in the inner chamber has ignited. Also at this time, the kiln will start producing bamboo vinegar through the chimney. At this point shut the fire hole.

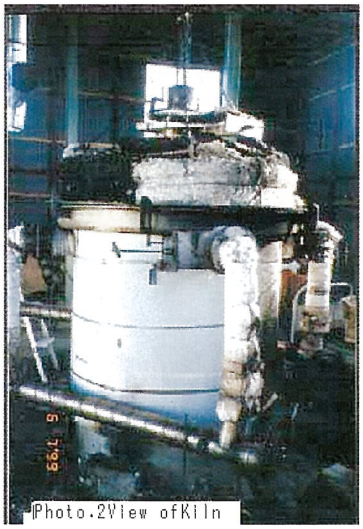

Figure 11

Figure 10

4. Carbonizing

Shutting the fire hole after the ignition of the bamboo will start the carbonization process. At this stage the kiln will produce more bamboo vinegar if the middle of chimney is cooled. This can be achieved by running water through a coiled pipe around the middle of the chimney, or by the use of a condenser. Minimization of smoke coming from the chimney can be achieved by using four air control valves described earlier in the text. After ignition of the bamboo it takes about 10 hours to complete the carbonization. The final stage of the process should be carefully controlled.

To achieve an optimum result the kiln must reach the correct temperature for the final carbonization process, (over 700°C). During this final stage, the chimneys should produce only a small amount of purple colored smoke. At this point you should close the shutter of the four side chimneys, and then open the main chimney shutter, and continue carbonization for approximately 20 - 40 minutes. After this, close the all of the air controls valves and the shutters to complete the carbonization.

5. Removing the charcoal from the kiln : see *Figure* 12

When the carbonization process is completed, and the load has cooled to room temperature, (usually about 10-15 hours), the bamboo charcoal can then be removed. Using a crane, remove the lid, and then remove the inner chamber (rostyle) from the main body. Place the inner chamber where you can conveniently empty the charcoal

Figure 12

f Quality control

There are many ways authorities use to test charcoal for its standard or quality. The method used by the KCP Katayama Company to test bamboo charcoal is by the sound that it produces. When hit lightly with a small hammer the quality can be determined by the sound it makes. We find that ideal bamboo charcoal achieves an electric resistance value under $10^7\Omega$.

g Bamboo charcoal yield

Used correctly the KCP Katayama Company kiln described here will yield 13-20 % bamboo charcoal (by weight) of the raw bamboo material. At the same time, it will yield 10-20 liters of bamboo vinegar. The quantities of each produced will depend upon the skill and experience of the operator, and the dryness of the bamboo chosen for carbonization.

5.2.2.2 High accuracy control temperature batch type carbonization device

The main disadvantages of these iron kilns are that they are expensive to build due to the cost of materials, and their construction requires a high degree of skill.

a. Summary

In recent times more people are becoming interested in wood and bamboo charcoal, because it is an important matter for the stability of CO_2 involving biomass resources and environmental purification. They are beginning to be used in many ways and not only as fuel.

Therefore, with a high quality of wood and bamboo charcoal in demand it is crucial that we develop the most efficient carbonization device. This device discussed has a different system of heating and controlling temperature from the regular one and thus is able to get a high quality yield. It also has the capabilities to carbonize various types of wood, such as thin wood, driftwood, wood chips and bamboo.

b. Specification

1) Physical appearance *(Figure 13)*

Figure 13

2) Main items

1. The type of carbonization device – (batch style with heating kiln using the machine outside)

2. Main heating method – (the wood has direct contact with the burning gas)

- The volume of the kiln - ($5M^3$)
- Temperature of carbonization – (The highest temperature is 800°C. It is possible to order a machine where the highest temperature is 1000°C)

3 Control method – (automatic sequential control with touch panel)

c. Characteristics

- By controlling the temperature very carefully you can get an excellent uniformity with the wood and bamboo charcoal.
- You only need a little fossil fuel for this because by using the heating reaction of the charcoal and the gas and sawdust wood can save energy.
- The procedure of carbonization is easy; simply enter the desired treatment condition dry, carbonized, or refined.
- There is no smoke pollution.
- You can move the device easily because it is compact.

Table 7 The Specification of High Accuracy Temperature Control Batch Type Carbonization Device

Type	KTC - I	KTC - II	KTC – III
The capacity of treatment (M^3/time)	2	4	10
The carbonization temperature (°C)	The highest temperature 800°C		
The measurements outside (m)	1.8^W x 4.5^L x 2.5^H	2.3^W x 6.0^L x 2.5^H	2.8^W x 6.0^L x 3.0^H
Electric used power (kW)	1.0	2.0	3.5

d. Price schedule (yen)
K T C - I\15,000,000 ~ 20,000,000
K T C - II\35,000,000 ~ 40,000,000
K T C - III\50,000,000 ~ 60,000,000

(notice) 1) Option : pyroligneous liquor collector, rapid cooling system, heat exhaust system, specification for the temperature of carbonization 1000°C

2) Specifications differ depending upon the design

5.2.3 Industrial Kiln

This method uses the crushed chips of the bamboo material. These chips are then placed in an industrial kiln, such as a moving floor or tilted rotary kiln, in a continuous carbonization process which takes a considerably shorter time. This method can produce a great amount of bamboo charcoal and bamboo vinegar in a short amount of time. However, crushing the bamboo destroys one of its finer qualities, which is its hard outer skin. So as a result, it produces a soft charcoal. It is possible to produce a harder bamboo charcoal with the industrial kiln by using pre-dried material, and by taking a little more time for the carbonization process.

The disadvantage of the industrial kiln is that it would need a large amount of money to improve it in order to produce high quality charcoal. These kilns were not originally designed for making high quality charcoal, but rather for making bamboo charcoal as a fuel substitute for wood charcoal. For this reason, the lack of heat resistance in the kiln's construction and lack of strength on the part of the moving floor would make the upgrading of the kiln too expensive.

5.3 The calculation of the economical efficiency of kilns

Since people have usually been making wood charcoal for fuel, the kilns in Japan were built to suit a particular type of wood and a particular carbonization method, rather than for the economical efficiency of the kiln. Therefore, there was no need to compare the economical efficiency of the different types of kilns. Though when used under similar conditions, and with similar materials for the same carbonization method, it is possible to compare each kiln's economical efficiency from the cost of the materials used.

Below is a sample of the calculation method used to calculate the kiln's profit (as is the case in Japan).

1) Calculate the product run ratio (%)

yield of charcoal (kg) / loading of charcoal (kg) x 100

2) Calculate the total output (per month)

If, for example,
the loading of charcoal (cut bamboo) is 12 kg,
the product run ratio is 30%,
the selling price is 4,000 yen/kg
and there are 23 working days/month, then:
12 kg x 30% (i.e. 0.3) = 3.6 kg
4,000 yen/kg x 3.6 kg x 23 days = 331,200 yen/month

3) Calculate the expense (per month)

personnel expenses (payroll costs)	150,000 yen
fuel	35,000 yen
material costs	15,000 ye
other consumable costs	30,000 ye
Total monthly expenses	230,000 yen

4) Calculate the profit (monthly)

Output - monthly total expenses = profit.
therefore...
331,200 yen - 230,000 yen = 101,200 yen.

By using these calculation methods, along with the information in *Table 8 No. 4* (*Handling Capacity* (*kg / run*)) and *No. 5* (*Yield of Charcoal* (*kg*)), it is theoretically possible to compare the economical efficiency of each kiln.

Table 8 A List of Kilns used for making Bamboo Charcoal and Bamboo Vinegar

1. User	2. Making Company	3. Kiln size (mm)	4. Handling capacity kg/run	5. Yield of charcoal (kg)	6. Yield of BPL* (litre)	7. Maximum temperature (°C)
Mud Kiln improved Miura type						
Obama Bamboo Char.Production Association	Own construction	1,50 high 3,000 deep wide	1,100-1,300	400-450	100-200	700
Mud Kiln Otake type						
Miyabicompany	Own construction	2,400 wide 3,000 deep 1,200 high	1,000	200-250	150-200	700
Fluid-bed kiln system						
Tachibana company	E-Ko-Company	-	8,000-10,000	1,200-1,500	200-250	-
Rotary Kiln						
Sikoku Techno Agri-corporation	SanwaTesuko Company	-	600	120	110	600
Fixed Stainless steel kiln						
KCP company	Kurosaki furnace making Com.	1,000 diameter 1,600 high 0.7 m volume	300	39-60	10-20	700
Fixed Carbonizer						
Kita-kyushu forest association	Itai furnace making Com.	2,800 wide 1,700 deep 2,120 high	600	120	240	200 oven 700 kiln
Batch type Carbonizer						
Obama Bamboo Char.Production Association	Yamane furnace making Com.	1,800 wide 4,500 deep 2,500 high	400	85	-	800

*BPL: Bamboo Pyroligneous Liquor

5.4 Quality standard of bamboo charcoal

Unfortunately, there is not yet an agreed quality standard for bamboo charcoal. However, I would like to recommend at least five procedures (shown below) which should be considered important to know when making high quality bamboo charcoal. Following the explanations of each procedure, there are charts with the actual measurements.

5.4.1 Bulk density and true density (synonyms for bulk gravity and true gravity)

A simple way to measure charcoal density is by using the bulk density measurement:

Bulk density = sample weight / (volume + porosity volume)

Although this value tends to be inexact, use this measurement method as well.

To measure the true density place the sample in a container, then attach the vacuum pump and remove the inside air for two hours. Then substitute helium (He) for the air removed. These measurements are used as volume and in the calculation of true density.

Table 9 No. 3 shows the true density values for bamboo charcoal and 'Bin-cho-tan' (hard wood charcoal). Wood charcoal's true density is usually around 1.8.

Table 9 General View of Bamboo and Wood Charcoal

Sample	TAKE-BC 600°C	TAKE-BC 800°C	TAKE-BC 1000°C	TAKE-BC 1200°C	OBM-BC	SIG-BC	CHN-BC	BNC-WC HYU
1. Bulk Density	0.43	0.48	not possible to measure		0.64	0.42	1.02	0.99
2. Apparent Porosity	72.1	71.4	not possible to measure		60.6	62.2	37.8	35.5
3. True Density								
- (Pycnometer)					1.44	1.42	1.44	1.46
- (He gas)	1.53	1.8		1.52	1.85	1.95	1.56	1.96
4. Specific Surface area [m^2/g]								
- (N_2 gas)	1.13	0.56	0	0	30.4	0.71	212	3.59
- (CO_2 gas)	221	255	0	0		322	181	98
5. Gas adsorption Characteristic [%]								
- H_2S	3.8		2.4			3.9		0.6
- NH_4OH	1.2		0.4			1.3		0.6
6. Humidification								
- H_2O vapor (2days)	9	6	5	2		7	6	4
- H_2O vapor (3days)	13	9	6	3.5	5.5	11	4.5	3.5

Measuring Condition:

1. Bulk Density and Apparent Porosity J I C 2141
3. True density
   Micromeritics Co accuracy 1330-03
   Gas Substitution method
4. Specific Surface Area
   Quanta Chrome Co. NOVA1200
   BET full Point Method
5. Gas Adsorption test
   Temperature 25°C, Atmosphere 1 item
   Used gas H_2S and NH_4OH Gas content each 2 5%
6. Humidification (Water Vapor Adsorption / Desorption test)
   Test condition 40°C, 40% and 40°C, 90% every day.

5.4.2 Industrial Analysis

These important values show certain characteristics of bamboo charcoal, including moisture, ash, volatile matter and fixed carbon. *Table 10* shows these measurements. The most important values are those of volatile matter and fixed carbon.

Table 10 Results of Industrial Analysis of Bamboo Charcoals

Carbonization method	Name of species	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)
black charcoal method	Moso-chiku*	5.1	2.2	15.5	77.2
(soft charcoal method)	Madake **	6.8	3.1	15.1	75.0
white charcoal method	Moso-chiku*	6.2	2.2	9.3	82.3
(hard charcoal method)	Madake**	8.5	3.1	9.9	78.5

* : *Phyllostachys pubescens* Mazel ex. Hauzeau de Lehaie
** : *P. nigra* (Loddiges) Munro var. *Henonis* (Bean)Stapf

Note that the hard charcoal method (white charcoal method), which uses a high temperature carbonization process, shows volatile matter at 9.3-9.9% and fixed carbon at 78.5-82.3%. On the other hand, the soft charcoal method (black charcoal method), shows a higher percentage of volatile matter and a lower percentage of fixed carbon.

5.4.3 Electro Resistibility (wood reforming frequency measurement device)

Electro resistibility for wood charcoal is advocated by Dr. Kishimoto. Using two terminals, with a regular interval and pressure on the charcoal surface, this measures electrical resistance. If 0 ohm (Ω) equals 0, then the ninth power 10 ohm equals 9. Most of the 'Bin-cho-tan' registers 0, and soft charcoal registers 1-9 using this method of measurement. In other words, if the bamboo charcoal carbonization process occurs at around 700° C, it will register 6-9, and if it occurs at around 1000° C, it will register 1-2. Therefore, it can be said that the electric resistance index (reforming frequency) shows the carbonization process frequency. These days, some people use the value of which the electric resistance value is divide by interval (ohm/cm) value without using the electric resistance as mentioned above. This data is one of the most important measurements used to judge the quality of bamboo charcoal, however, in order for it to work properly it must be measured correctly.

5.4.4 Hardness (Miura method of wood charcoal hardness meter)

The Miura method of wood charcoal hardness meter, measures Mohr Hardness, using a type of scratch hardness meter. Using this hardness meter, steel registers 20, and lead registers 1. 'Bin-cho-tan' usually registers at 15-20 and bamboo charcoal between 1-3.

5.4.5 Specific Surface Area

The surface microstructure of bamboo charcoal is revealed by using gas adsorption to examine the specific surface area. Additionally, during the process of calculating the specific surface area, the isothermal adsorption is also calculated. By analyzing this data, one can plot a pore distribution map of the charcoal. The pore distribution map, along with the specific surface area of the bamboo charcoal, shows the adsorption capacity of the charcoal for gas or liquid.

Table 9 No. 4 shows the specific surface areas of several qualities of bamboo charcoal, using several different temperatures during the carbonization process. In this experiment it was found that the BNC-WC HYU ('Bin-cho-tan') surface area was $98m^2/g$ with CO_2 gas. On the other hand, the TAKE-BC (bamboo charcoal) surface area was $255m^2/g$ at 800° C with CO_2 gas, which is more than two and a half times the specific surface area of BNC-WC HYU ('Bin-cho-tan').

From this study, we have considered five important procedures used to determine the quality of bamboo charcoal. Although they do not cover every area of quality, they are representative of the important procedures for identifying good charcoal. When considering new multipurpose uses for bamboo charcoal, which has more than ten kinds of uses other than fuel, the same quality standards do not necessarily suit the different purposes.

Chapter VI : Sara Buri RFD

Improvement plan for Charcoal Research Centre, Small Sample Brick Kiln

6.1 Introductory Research

Sara Buri is located about 100 km northeast of Bangkok, the capital of Thailand. In Sara Buri the Charcoal Centre is managed and run by the Royal Forest Department (RFD). On the property there are 10 brick charcoal kilns of various sizes. I was informed that all of these brick charcoal kilns were installed about 22 years ago for the making of charcoal as fuel.

The charcoal that I saw there was made from bamboo. This test bamboo charcoal was made using the smallest of the 10 kilns (volume 1 m^3). The bamboo charcoal samples A-1, B-1, A-2 and B-2 were then taken to Japan to examine their properties and characteristics.

At this time I am still waiting on a detailed analysis on the properties of the test bamboo charcoal, (sample A-1, B-1, A-2 and B-2). However, the results of their electrical resistance and hardness are tabulated as follows in *Table 11.*

Table 11 Bamboo Charcoal Characteristics

SAMPLE A-1, B-1, A-2 and B-2

From RFD (Royal Forest Department) Sara Buri Charcoal Research Centre, small sample brick kiln.

Name of Bamboo Material Species	A-1*	B-1**	A-2*	B-2**
Date of Product	12.21.01	12.21.01	12.13.01	12.13.01
Maximum Carbonization Temperature (°C)	600	600	500	500
Electrical Resistance Ω	1M>	1M>	5-6M	1M>
Hardness meter*3	1	1	1 - 2	1

* : Species is Unknown 1
**: Species is unknown 2
*3 : Japan charcoal standards

As outlined in *Table 11* there were two tests of the carbonization process. The tests reached the maximum temperatures of 600°C and 500°C respectively. *Table 11* showed that the electrical resistance on all samples was higher than 1MΩ. *Table 11* also shows the hardness was more than 1 on both occasions. This demonstrates that the kiln produced only soft bamboo charcoal. Additionally, after the two-test carbonisation processes were completed, a noticeable percentage of the bamboo charcoal had not been fully carbonized.

The findings in *Table 11* also indicated that the small sample brick charcoal kiln tested used the conventional method of carbonization, and seemed suitable enough for making charcoal just for fuel. However, it was found unsuitable for making so called 'multipurpose' charcoal from either bamboo or timber. The market for 'multipurpose' charcoal is flourishing in Japan.

My desire however is not to criticize the sample kiln by pointing out its problems. Rather, I see my role is to evaluate how best to make the full use of this kiln, and to suggest any worthwhile improvements. The following passages reveal my suggestions.

6.2 Improvements of the small sample brick charcoal kiln at RFD.

When I studied the small sample kiln at Sara Buri RFD, I noticed that there were two kinds of bamboo species being mixed together for sample charcoal material tests.

First, I want to suggest how to improve the small sample kiln's output. Its operators should be able to reach the more ideal maximum carbonization temperature of 700°C. This should be achieved with the full adoption of the following five improvements.

The following is a list of five first stage improvements for the small sample kiln. These improvements are listed in headings, which are then followed by a full explanation. After full implementation of the five first stage improvements, a second stage follows. These two, second stage improvements are listed in heading form and are also followed by a full explanation.

At this point, I would like to make it clear that the recommendations below should show an improvement in the performance of the sample small kiln. However, this is not to suggest that the same recommendations will necessarily show an improvement in the performance of all the larger kilns. The larger kilns would need to be assessed for their own specific requirements.

6.3 The First Stage Improvements - Five Sections:

6.3.1 Build a removable inner fire hole cover/buffer.

The C type section shaped removable inner fire hole cover should be located against the inside of the fire hole of the kiln, 30 cm from the entrance. (See *Figure* 14)

Fortunately, a prototype removable inner fire hole cover was completed and used during my third visit to this kiln. This addition is intended to help the load to ignite faster and burn more evenly. This should also reduce the amount of over burnt wastage on the external surface of each load.

6.3.2 Install a rostyle (inner chamber) in the bottom of the kiln.

Install a rostyle with its base plate 5 -7 cm from the bottom of the kiln. This should improve airflow to help the load to ignite faster and burn more evenly. This will produce a bamboo charcoal of improved uniformity and quality. (See *Figure* 16)

6.3.3 Extend the length of chimneys.

Generally, it is said that for a kiln with a single chimney, the chimney height should be 2 to 3 times the height of the kiln. But, if for example four chimneys are used, this height should be divided by four.

The small sample kiln examined at RFD has a unique design and structure when compared to Japanese kilns. For this reason, it should not follow the general chimney height formula exactly.

At present, the small sample kiln examined at RFD has four 45 cm chimneys. In my opinion, the height of all four chimneys should be increased so that the total height of each is between 100 and 150 cm. I would also recommend support posts for each of the chimneys due to the increased height. (See *Figure* 14, 18)

Additionally, with the small sample kiln I recommend installing a vinegar collection opening at each chimney's mouth. (See *Figure* 15) It is recommended that all the chimneys and the vinegar collection openings be made of stainless steel. This is because in the carbonization process, bamboo produces acid smoke, and stainless steel is acid resistant. If stainless steel is not feasible, it is possible to use bamboo for the same purpose by trimming its joints.

6.3.4 Selection and sorting of bamboo.

At the small sample kiln at Sara Buri RFD, I noticed that there were two kinds of bamboo species mixed together for sample bamboo carbonization tests. It should be pointed out that this is unwise. There should only be one species in any individual load being used for carbonization. This is becuase properties and characteristics vary between different bamboo species.

At this point, it is also worth noting that when you load the charcoal material into the inner chamber, there are two loading methods. The first method is by arranging the bamboo standing upright from top to bottom. The second method is by arranging the pieces parallel to the bottom. The method chosen should be determined by the shape of the kiln inner chamber.

With the small sample kiln, it is cylindrical, so to maximize its capacity it is obviously best to use the upright loading method. For this reason the bamboo should be cut* lengthways (like a pie diagram) into four 'quarter' pieces, or six 1/ 6 pieces. Whether cut into 1/4 or 1/ 6 pieces, each piece should have a total length, which is 10 cm shorter than the kiln's inner chamber height. (See *Figure* 14, 18)

The prepared bamboo pieces can then be loaded neatly into the inner chamber. It is important that the loading be done reasonably tight and uniformly. A load prepared this way will then ignite evenly and conduct heat well. This will produce uniform and good quality bamboo charcoal effectively without much loss.

It is not advisable to use any short bamboo pieces or chips in the carbonization process. Doing so will result in bamboo charcoal without the strength of the lengthways fibers which is an important property of bamboo charcoal.

*A bamboo-cutting tool is available in Japan for this task. This tool makes cutting the bamboo much faster and easier. (See *Figure* 16)

6.3.5 A stronger ignition at the start of the carbonization process

After loading the raw bamboo material reasonably tightly and uniformly into the inner chamber of the kiln, ignite the material by using starting fuel in front of the new removable inner fire hole cover.

A good strong ignition does not require a specific fuel. There are many available choices. The most important thing is to achieve strong ignition.

Strong ignition of the now loaded bamboo is the first important step required to perform a uniform, good quality carbonization. Strong ignition will produce powerful suction via the opened air valve, through the inner chamber, and all the way through to the chimneys. The resulting powerful air movement around the bamboo load will produce the necessary rapid increase in burn heat. This will get the bamboo load to the required temperature quickly, and ensure quick and constant progression of the burning process.

Achieving strong ignition, an extremely hot air flow, and correct temperature burn heat is also important for another reason. There are volatile gases produced inside the bamboo during carbonization. The burn heat created inside the inner chamber will ignite these volatile gases.

Let us look at the situation where the ignition, and therefore the burn heat are insufficient. If this occurs, there will be a reduction of airflow from the opened air valve to the inner chamber, and all the way through to the chimneys. Even though the load has ignited, the kiln cannot reach the necessary temperature for an even proper burn or uniform carbonization.

In addition, in this low heat situation, if the air valve is closed you cannot expect the load to achieve the required thermal decomposition. In this case, even though the process has occurred, the actual carbonization process has not been finishedcompletely or evenly.

When researching the small sample kiln in actual operation, at Sara Buri RFD, a few simple observations were made. The ignition method used appeared to be far too weak. Because of this, the load inside the kiln would not have been able reach the necessary temperature for proper even burning and uniform carbonization.

Table 11 supported these observations. The small sample kiln did not reach the required temperature during testing. This produced a considerable amount of low grade, partly carbonized, soft charcoal.

Intermediate Notes:

The five separate sections of Stage One should be thoroughly researched until an optimum result has been found. Only after this has been done should the two sections of stage two be commenced.

Table 11 showed a basic analysis of the carbonized samples from the two test sessions at RFD. It would be difficult to recommend further improvement plans without more data. However, adopting the recommendations outlined in this report should increase the maximum heat inside the kiln. This is because the structure of the small sample kiln tested at Sara Buri RFD was built with brick, which retains heat well.

After adopting the first five improvement recommendations of stage one, two thermo-electric temperature censors should be installed. One censor should be placed at the top while the other one at the bottom of the kiln. When the maximum temperature of the bottom sensor reaches over 500°C, the two recommendations of stage two should then be attempted.

6.4 The Second Stage Improvements – Two Sections

6.4.1 The preliminary drying of bamboo

A simple way to increase the yield of bamboo charcoal is by pre-heating the bamboo. To do this, put the correctly cut (preferable but not essential) raw bamboo pieces into the dryer and blow with hot air at 180 to

200°C for about eight hours. The now air-dried bamboo should then be loaded into the kiln for the normal carbonization process.

Normally this operation would require the installation and use of a dryer. However, for experimental purposes it is possible to use a spare unused kiln for the same purpose. It should be expected that this preliminary drying of the bamboo would speed up the primary stage of the carbonization process, and increase the yield.

6.4.2 Operating reforming

The process of 'operating reforming' is when during the final stage of carbonization, with the kiln maintaining a stable high temperature, the air valve is opened a little. Only after the six sections (Sections 1-5 stage one and Section 6 stage two) have been thoroughly tested and have demonstrated evidence of a quality improvement, should this final section 7 be attempted. When performed correctly 'operating reforming' can produce a higher quality bamboo charcoal.

Important

Operating reforming will rapidly increase the temperature inside the kiln causing abnormally strong combustion. If this operation is performed wrongly, there is the possibility of the top of the kiln exploding. Therefore, it is potentially dangerous to kiln operators.

The above-mentioned Sections 6 and 7, require the use of additions such as the installation of the bamboo dryer, and an air valve on top of the kiln. These modifications and their correct operation will be more fully described in the official report.

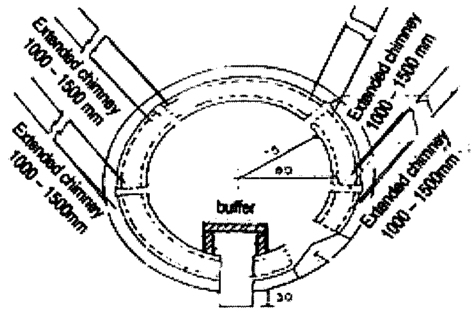

Figure 14 Removable fire holecover/buffer and the extended the length of chimney

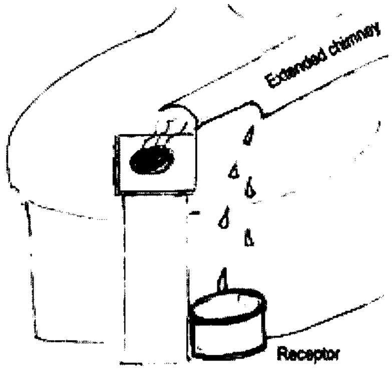

Figure 15 Chimney connection

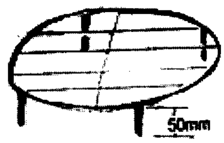

Figure 16 Rostyle

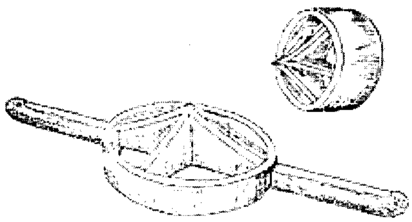

Figure 17 Bamboo cutting tool

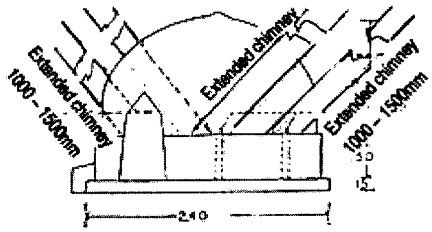

Figure 18 Extend the length of chimney

The Figures of improvement plan for Charcoal Center Small Brick Kiln

The next page showed results of analysis of bamboo charcoal.

Table 12 Technical Analysis of Bamboo charcoals

RFD (Royal Forest Department) Sara Buri Charcoal Research Center Small Sample Brick Kiln

Name of Bamboo Material Species	A-1*	B-1**	A-2*	B-2**	Moso-chiku
Date of Product	12.21.01	12.21.01	12.13.01	12.13.01	
Maximum Carbonization Temperature (°C)	600	600	500	500	600
Electro Resistance Ω	M>	M>	5-6M	M>	10^4
Hardness meter***	1	1	2-3	1	1-3
Moisture content (%)	2.1	2.0	4.2	3.9	5.1
Ash content (%)	11.3	6.6	7.8	10.7	2.2
Volatile components (%)	13.3	10.3	16.3	8.6	15.5
Fixed carbon (%) content	73.3	81.1	71.6	76.8	77.2
Apparent density*4 (g/cm^3)	0.83	0.58	0.47	0.59	0.42

* : Unknown 1

** : Unknown 2

*** : Measured by Japan Charcoal Hardness Meter

*4 : Apparent density = mass weight (g) / substantial volume +apparent close pore volume (cm^3)

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