Pyrolysis as a waste technology: perspective and issues

Y. Shinogi
Department of Agriculture and Environmental Engineering, National Institute for Rural Engineering, Japan

Abstract

We have been conducting research on pyrolysis, its manufacturing technology and the use of carbon products with the objective of promoting pyrolysis as a recycling technology. The merits of pyrolysis include 1) reduction of weight and volume, 2) reduction of bad odors, and 3) increase in handling capability, etc. The degree of merit depends on the source materials and process utilized. The main characteristics of the carbon products are 1) lightweight, 2) porous media, 3) black body, 4) alkaline, etc., which are dependent on the source materials and pyrolysis conditions, such as temperature. The carbon products are mainly used for agricultural soil improvement and deodorizing materials, etc. The pyrolysis process creates carbon products and generates power, thus making it possible to achieve sustainable material circulation systems.
Keywords: pyrolysis, biomass, organic waste, carbon product.

1 Introduction

Material circulation is essential for building a sustainable society, and recycling technologies are key factors. However, some of the difficulties encountered in approaching this goal are directly related to these recycling technologies. For example, some recycling methods require a large budget to build, operate and maintain the facilities, some are not environmentally friendly, and some require a large space and long operation time, etc.

In Japan, although incineration is the most popular recycling technology, it faces extensive criticism over the emission of dioxin gases in the process. In addition, composting is not widely used mainly due to space and time limitations and problems regarding excess nitrogen, etc. There is a high demand for the development of optional recycling technologies.

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We have proposed “pyrolysis (carbonization)” as a promising recycling technology, without types of activation. Wood char has been used since ancient times (e.g., Abe [1]) as well as other popular materials in Japan, and pyrolysis is a familiar technology in the country. Activated carbon made from organic resources such as palm crust is also commonly used in Japan (e.g., Abe [1], Toles et al. [4]). However, carbon products other than activated carbon are not widely used (JA report [2]) and are not readily accepted worldwide. We proposed pyrolysis using organic (waste) materials, namely “biomass”, for which few studies have been conducted.

We have been studying both the manufacturing and usage of pyrolysis and carbon products from biomass, and it is now necessary to bridge the two sides (Shinogi et al. [6], Shinogi and Kanri [5]).

This report outlines the process, merits and demerits of pyrolysis, and the perspectives and issues. Finally, the ongoing research project is briefly described.

This study and related information mark a milestone in related research fields and should be made available to developing countries for future use.

2 Pyrolysis and carbon product

2.1 Pyrolysis

Pyrolysis is the process of heating with little or no oxygen supply, which differentiates it from the process of incineration. Pyrolysis is the process of generating available carbon products by heating organic resources. For example, in the process of manufacturing wood char, at around 200°C, decomposition of cellulose, hemi-cellulose and lignin starts. At around 400 to 600°C, various characteristics such as pH, EC, etc. begin to change. For example, regardless of the initial pH of the source materials, the pH increases gradually with increasing temperature at around 400°C, then increases significantly to 600°C, after which it changes greatly.

The merits of pyrolysis are: 1) reduction of weight and volume, 2) reduction of bad odor from ammonium and other kinds of odorous gas, 3) improvement of handling characteristics, etc. Of course, the degree depends on initial conditions such as initial water content, etc. There are many types of pyrolysis facilities depending on the method of heating (internal or external), process type (batch or sequential), style (horizontal or vertical), etc.

2.2 Carbon product

The main characteristics of carbon product are: 1) lightweight, 2) porous media, 3) black color, 4) mainly alkaline, etc. The characteristics of the carbon products differ significantly depending on the source materials, pyrolysis conditions such as manufacturing temperature, temperature increment, holding time and type of pyrolysis facilities, carbonization oven type, etc. Mainly, pH and surface area index (surface area per unit area) increase with manufacturing temperature, while the yield decreases and the density does not change with temperature.

There is still no clear definition of carbon products (manufacturing temperature, properties, manufacturing process, etc).

3 Uses

3.1 Carbon products

Carbon products are used for various purposes. For example, for agriculture, wood char is used for soil dressing to improve soil physical characteristics such as permeability, water-holding capacity, density, etc. because wood char is light, porous and can absorb water easily. For example, carbon product from bagasse (sugarcane squeezed residue) can hold almost five times the amount of water. The impact depends on the application rate of the carbon product and the texture of the soil with which it is mixed. For example, there is a bigger improvement in soil physical properties such as water-holding capacity and permeability for clay soil, while there is no significant impact for sandy soil.

Recently, Shinogi and Kanri [5] reported that phosphorous and potassium remain in the carbon products from waste sludge such as sewage and cattle sludge. These components are water-soluble and citric-soluble, and can be easily absorbed by crop roots. It is expected that application of the carbon products from sludge, especially in terms of the phosphorus component, might enable the amount of chemical fertilizer used to be reduced. Several studies such as Shinogi et al. [6] are related to this.

We expect the application of carbon products, mainly from sludge, to bring about improvement of not only the physical properties of soil but also the nutrient conditions of the crop root zone.

Since ancient times, wood char has been used as a deodorizing material. The surface area index of carbon products from sludge is much larger than that of wood char. But the carbon products from sludge can absorb various kinds of odorous gas such as ammonium, methyl-mercaptan and acetaldehyde (Yasumura and Iyasu [7]). The performance of the deodorizing function does not depend on only engineering properties such as surface area index but also on other surface chemical features such as ionic charge, etc. Shiratani et al. [8] showed that carbon products do not contribute to purification of water quality. It works the same as those of ordinary contact purifying materials, and the function depends on the water load (carbon volume to total water discharge). It is reported that carbon products enable purification of poor water quality.

In addition, some carbon products are used in iron manufacturing. Carbon products are also now sold as art and commodity crafts in specialty stores, for example, artificial vessels, art objects, etc. Especially in Japan, there has been a boom in carbon products.

3.2 Energy use

Pyrolysis is used as an energy generation method, mainly for electricity through turbine engines. In Japan, there are several pilot-scale power generation plants using pyrolysis (Yakushido [9]). The main source materials are cattle sludge, etc.

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Organic waste products such as sludge, agricultural residue and waste oil, could be used as useful source materials. However, various issues must still be resolved to improve efficiency because carbon content of the source material, biomass, is usually not very high.

4 Issues

Pyrolysis is a promising recycling technology. However, its full use has not yet been achieved and there are some remaining issues for improvement. These are outlined in the following sections.

4.1 Efficiency and performance

There are various methods for generating carbon products in terms of energy input (inertial and external), process type (batch and sequential), style (vertical and horizontal), etc. To date, not enough studies have been conducted on improvement for efficient manufacturing processes. Generally, in making carbon products from biomass, external energy is necessary and the total input energy depends on the source materials, initial water content, etc. There are many efficiency factors that require improvement, such as saving input energy, improving thermal coefficient, sealing, etc.

We created a pilot pyrolysis plant (facility), which utilizes recycled gas with activation operation. The areas that still require improvement include defining the maintenance characteristics, such as how long the oven will last and what kind of maintenance is necessary.

It is also necessary to determine the uniformity of the carbon products. Of course, carbon products differ depending on the source materials, and biomass is basically non-uniform and therefore it is difficult to expect higher uniformity. However, it is important to show the variation depending on source materials and pyrolysis process (plant type).

Basically, input energy depends on initial water content; therefore it is necessary to minimize this, at a low cost, but this is not easy. For example, how can we reduce the initial water content of sewage sludge? Solar energy is a promising energy resource, but there are limits to the duration of utilizing natural energy. It is necessary to develop optimal process systems.

4.2 Evaluation

Process systems must be evaluated from an economic standpoint, but in such a case, pyrolysis is not always feasible because input energy is required. If carbon products were highly economical, it would be economically feasible, but this is rare. At this time, pyrolysis is not economically feasible.

In evaluating pyrolysis more extensively, pyrolysis produces little dioxin gas emissions and carbon products are sometimes recycled and reused properly, resulting in an indirect reduction of environmental impact. Unfortunately, this factor has not yet been taken into consideration. Proper evaluation methods are needed, such as LCA (life cycle assessment), which is a very useful and important concept in this case.

It is also necessary to clarify the definition of carbon products, the minimum and maximum temperature, hardness, components, etc., and to define indicators of carbon products.

4.3 Environmental impact

As previously mentioned, the pyrolysis process emits a small amount of dioxin gas and it is easy to reduce gas emissions such as NOx and SOx if they are disposed of properly.

A gas filtering system, such as a bag filter, is a useful technology for reducing environmental gas emissions.

Pyrolysis is expected to reduce environmental impact (load) because recycling of the materials reduces the purchase of new products and therefore indirectly reduces environmental impact.

4.4 Acceptance

In Japan, wooden char is commonly used, but the pyrolysis process is not very popular. It is important to inform those concerned of the importance of material circulation and the capabilities of pyrolysis. It is also necessary to manage waste products properly. Because the nature of the carbon products is highly dependent on the source materials, source materials management is important. Research must be conducted on these issues.

Furthermore, any heavy metals and hazardous materials in carbon products should be completely removed from the source materials.

Regarding application of carbon products to farmland, defining the optimal application rate is quite important. Content increases with temperature, and with continuous application some contents may accumulate and increase in amount. Even though there is a safe level for the application, continuous applications may exceed the limited content. Determining the optimal application amount is necessary.

4.5 Miscellaneous

Recycled materials such as carbon products and compost are not always readily accepted by farmers and consumers. It is necessary to achieve a comprehensive framework and regional society. For example, systems for collecting waste products and delivering recycling materials are necessary. Reliability of producers (farmers) and consumers is necessary. Basically, achieving social acceptance is necessary in certain areas. Therefore, collaborative study on natural science, social science and engineering is necessary, and the involvement of stakeholders and citizens is essential.

5 Material circulation systems based on pyrolysis

In FY 2004, the MAFF (Ministry of Agriculture, Forestry and Fisheries, Japan) started a 3-year pilot model research project on achieving material circulation. Biomass exhaust differs from region to region; therefore suitable material

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circulation systems differ among the regions. The MAFF selected several cases in which pyrolysis is one of the key recycling technologies; one is a close tropical island and another one is mainly a business-dominated region close to a metropolitan city; the former is Miyakojima Island and the latter one is in the northern part of Chiba.

The case of Miyakojima is briefly introduced. This island is located in the southern part of Japan, has a semi-tropical climate, and agriculture is the dominant industry. Sugarcane and beef are both main products, and therefore sugarcane residues such as bagasse, dehydrated cake, waste sugar syrup, etc. and cattle sludge is the main target for waste organic materials. For these waste products, pyrolysis and methane fermentation technologies will be selected for disposal and recycling. In the pyrolysis process, power generation and manufacturing of carbon products are expected and in the methane fermentation plant, power generation is expected and fermentation solids and liquid residues are expected to be recycled. Mainly, the carbon products and methane fermentation residues would be mixed with the farmland soil to improve its physical and chemical properties (fertility).

In the project, full-scale pyrolysis and methane fermentation plants will be constructed and material circulation would be promoted.

Environmental loads, mainly nitrogen and carbon, development of optimal pickup-delivery systems, and optimal evaluation systems taking into consideration reduction of environmental impact will be monitored. In addition, social science studies such as increasing the social acceptance of recycling or material circulation will be conducted using visualizing technologies (GIS).

6 Conclusions

We have proposed pyrolysis as a promising recycling technology to support traditional methods. Now that the preliminary research stage is finished, we are moving toward its actual use. While the pyrolysis process has not yet been perfected, it does enable the promotion of material circulation with the objective of achieving a zero-emission society. However, more research must be conducted to achieve this goal.

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