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AN ENVIRONMENTALLY HARMONIOUS ORGANIC WASTES RECYCLING SYSTEM

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Abstract

This research has been performed with the aim of establishing a recycling system for minimizing the load of organic wastes to the environment. As a first step in achieving that type of "circulatory" society, proposes a method of circulatory recycling targeting in particular organic wastes from food sources. Initially, aerobic fermentation methods such as "composting" and the "thermophilic oxic process (TOP)" will be detailed as the important elemental technology and the effectiveness and methods of efficient operation will be discussed based on the experiments. Next, on the basis of the experimental results, the possibilities of the organic waste product recycling system will be introduced as well as new proposals for the design and operation of the fermentation. It should be noted that society as a whole is tending towards being a recycling society or environmentally symbiotic society in response to global environmental problems and the current inability of modern industrial society.

KEYWORDS: *organic wastes, recycling system, composting, thermophilic oxic process*

1. Background and aims of the research

Although the effective use of resources and the reduction in environmental load is one of the most important problems facing us today, materials flow in our modern industrial society is in a one fixed way: [production]→[distribution]→[consumption]→[disposal]. As this path is lacks a process equivalent to the natural ecological "decomposition" and "recycling" steps and there is no pathway from disposal back to production and distribution, it is difficult to prevent the large-scale resource consumption and a high environmental load (Naito, 1998). The world conference (COP3) related to global warming held in Kyoto in 1997 reiterated that environmental problems on a global scale originate from this fixed mass production/consumption structure. Thus in response to the current industrial society, the whole world is searching a suitable way for a change to a new society incorporating wastes recycling and environmental symbiosis.

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The first step to realize this recycling system is to propose the recycling and utilization of organic wastes from food sources. In order to achieve this, firstly the aerobic fermentation method such as "composting" and the "thermophilic oxic process (TOP)" will be detailed as the important elemental technology and the effectiveness and methods of proper operation will then be discussed based on various experiments. Next, based on the experimental results, the possibilities of an organic wastes recycling system will be introduced as well as new proposals for the design and operation of such a system.

2. Significance and a way of re-constructing a regional organic material recycling system

In order to avoid the above-mentioned resource consumption and environmental loads present in today's large-scale industrial society, attempts aiming at zero-emissions are being carried out in all production and household processes. Needless to say however, the key to achieving this is relying on how to revive the recycling system. While in the past, the flow of organic matter from food sources suitably revolved around a natural ecological circulatory mechanism, this is now in ruins. While there are various causes for this, the foremost is the influx of low price livestock raising and fertilizer as a result of international trade. Furthermore, sources of wastes have been mass concentrated due to population concentration in the cities while the siting of the livestock sector that receives such wastes further away from urban areas is another major cause. Accordingly, the reconstruction of the "man and nature in symbiosis" society system is a prerequisite when aiming for the reuse of material circulation.

In this way, it is of great importance that organic material circulation is a system that maintains the balance between human life and the natural eco-system. Thus natural systems of agriculture, livestock and forestry as well as the urban and industrial man-made systems must be balanced combinations. Accordingly, by looking at "generation processes of organic material related to the food industry", "sewage disposal processes from urban wastewater treatment" and "composting processes of feces and urine from livestock industry", one can assemble actual data from model examples of each. Based on that data and assuming a new regional structure where there is cooperation between urban and rural activities (functions), one can find a policy for re-establishing an organic wastes recycling system that relates to the various processes besides the proposed ones.

The system proposed by this research based on the above ideas, is an organic material circulation involving "the household", "the food industry", "the livestock industry" and "the agriculture". Firstly, food products from the food industry are supplied to the outlets and the food by-products and wastes rich in nutrition are passed on to become livestock feed. This livestock waste is then converted into fertilizer together with the sewage sludge from the household wastewater treatment process and returned to agricultural land. Thus circulation is completed by the agricultural products produced there being returned to society once again.

Prior to suitably plan this kind of recycling system, it is necessary to conduct an intensive survey of the flow of organic wastes generated from each industry in the region as shown in figure 1. Based on this data, the optimum decomposition, and the development of the necessary recycling technology and the optimum system arrangement incorporating these for most effectively utilizing each kind of

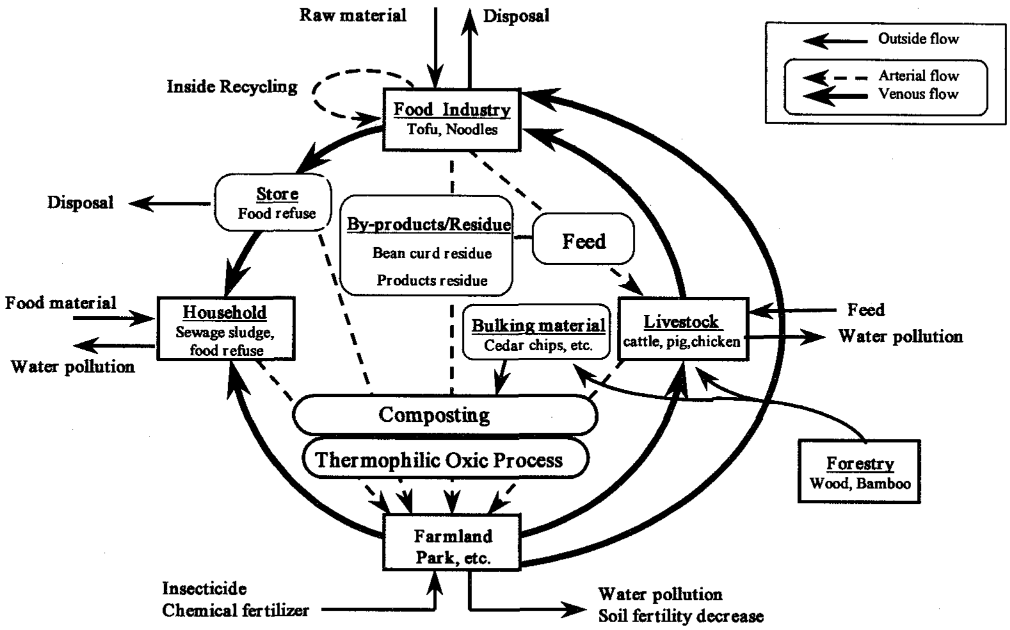

Figure 1. Flowchart of organic material recycling system

organic material can be identified. As a core technology, it is considered that microbial processes (in particular the composting and the thermophilic oxic process) were indispensable and if these are used, the combination and suitable distribution of a variety of organic materials from households and food industries for optimizing the decomposition and recycling process features become important key technological areas.

3. Investigation and experimental procedures

Field and experimental data are collected and analyzed in accordance with the following procedures.

① Firstly, the flow of organic wastes in the region concerned generated from the food industry, distribution processes and households are investigated thus determining the state of the organic wastes.

② The "composting" and the "thermophilic oxic process" which the authors here chosen as elemental technology contributing to the circulation of organic waste material are investigated on the reaction characteristics experimentally.

③ Based on the results, an analysis is made of finding the design and operation strategy of the two processes depending on the quality and quantity of the raw materials.

3.1 Current state of the generation and flow of organic waste materials

As shown in Table 1, yearly production at the model food plant concerned is 30,000 tons. The so-called by-products generated during the food production process such as bean curd residual, bread residuals and pot sticker residual amount to 27% (8,167 tons) of the production amount meaning 267kg of by-products are generated for each ton of product. 70% of the by-products are currently used as feed material with the remaining 30% disposed of as industrial waste. Table 1 shows generated amounts and states of by-products at the food plant. The waste cooking oil generation rate in relation to the amount of fried food products is 26.5% and at this plant, 380 tons of waste frying oil are returned to contractors every year. Table 2 shows the details of each by-product and shows that the majority has water content of over 50% and that the organic content (VS) is high.

Table 1 The amounts and state of food by-products from A-Coop food plant as a model unit

Products	Production (tons/year)	Food by-product	Amounts (tons/year)	Generation Rate (%)	Generation frequency	Shape
Tofu varieties	8499	Bean curd residual	6500	76.5	Daily	Damp powder
		Tofu residual	350	4.1	Daily	Damp solids
Fried food	1432	Residual	90	6.3	Daily	Product
		Waste frying oil	380	26.5	Once 3 days	Oil
Noodles	5912	Boiled noodle residual	160	2.5	Daily	Product
	583	Raw noodle residual	10	1.7	Daily	Product
	269	Pot sticker residual	150	55.8	Daily	Ribbon shaped
Konnyaku	2548	Residual	40	1.6	Daily	Product
Fermented soybeans	916	Residual	40	4.4	Daily	Product
Bread types	5880	Residual	410	7.0	Daily	Product
Sweets	4551	Residual	47	1.0	Daily	Solid

Table 2 - The characteristics of food by-products from A-Coop food plant as a model unit

Food by-product	Calories (kcal)	Water content (%)	Protein (%)	Lipids (%)	Carbon-hydrates (%)	Ash (%)	VS (%)	Hs/Hw
Bean curd residual	89	81.1	4.8	3.6	9.7	0.8	95.8	1.9
Tofu residual	77	86.8	6.8	5	0.8	0.6	95.5	1.5
Frying Residual	388	44	18.6	33.1	2.9	1.4	97.5	15.1
Waste frying oil	921	0	0	100	0	0	100.0	
Boiled noodle residual	101	76.5	2.5	0.5	20.4	0.1	99.6	2.3
Raw noodle residual	280	33	6.8	1.3	57.1	1.8	97.3	14.6
pastry residual	368	42.6	5.3	1.1	50.5	0.3	99.5	14.8
Konnyaku Residual		9.8	2.9	0.1	81.6	5.6	93.8	
Soybeans Residual	200	59.5	16.5	10	12.1	1.9	95.3	5.8
Bread Residual	260	38	8.4	3.8	48.1	1.7	97.3	11.7
Sweets Residual	--	--	--	--	--	--	--	--

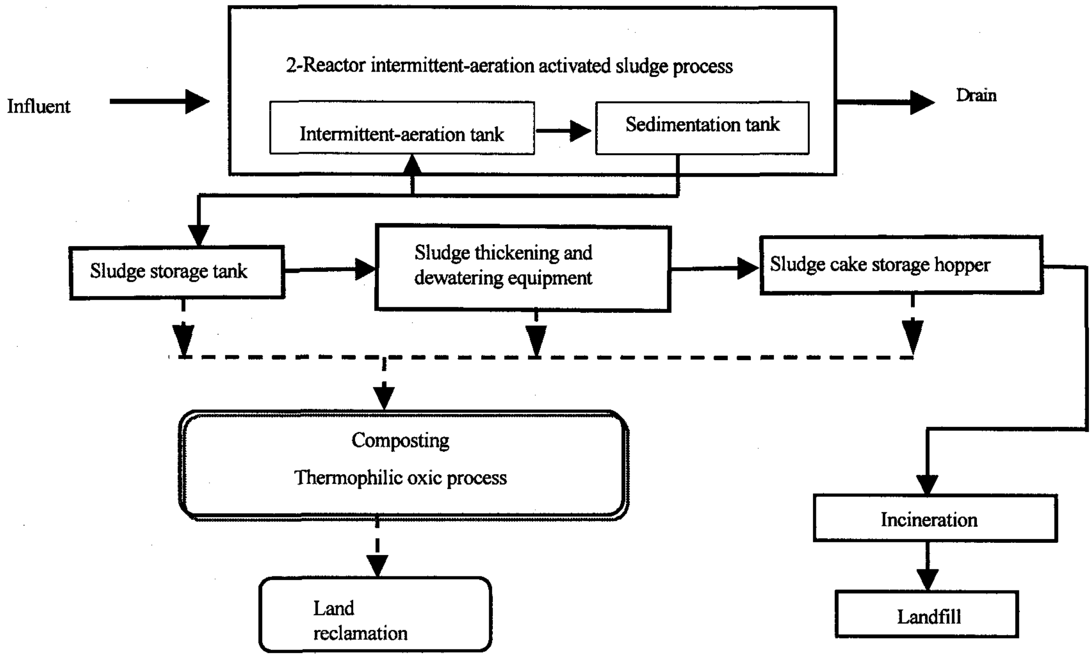

Figure 2. Process flow of the test plant

Table 3 The characteristics of sewage sludge and waste cooking oil

Items	Water content (%)	VS (%)	BOD_5 (mg/l)	T-N (mg/l)	Calories (kcal/kg-ds)
Excess sludge	99.2	70.8	1200	530	4460
Thickened sludge	95.4	70.9	100 (mg/g-ds)	84.2	4500
Dewatered sludge cake	77.6	70.2	93 (mg/g-ds)	84.2	4375
Waste cooking oil	--	100	1,365,000	--	9487

Waste material in the "distribution process" refer to food products received at the market being disposed of unsold when the price drops suddenly or the product costs decrease due to damage during transportation. Waste material in the "sales process" refer to products that are still suitable for consumption but are disposed of or incinerated for legal or hygienic reasons related to their sell-by dates or time limits. These food refuse products are disposed of as food refuse from the retail outlets and represent about 1.0% of the total food supplied to the outlet. As the composition of this waste material differs from day to day, the nature is unstable but the average water content is 87～90%.

Of the (yearly) 4000 tons of food refuse generated by the retail outlets, approximately 30% (1,333tons) becomes fertilizer material. This is dependent on agricultural limitations such as permissible levels for acceptance by the farm. By the addition of 667 tons of by-products (husks, sawdust, used coffee beans etc.), the water content and ventilation ability are adjusted and by speeding up the decomposition of easily decomposable organic materials, 1,000 tons of organic fertilizer can be produced. It should be noted that from the results of composting experiments using food refuse from the outlets, the measurable levels of arsenic, cadmium and mercury in the compost were drastically lower than the harmful material standard values of fertilizer and as the effect on the soil can be ignored, the organic fertilizer produced by the composting is applicable to agricultural land and the harvested products can be supplied to outlets.

Next, in the households of the region related to the previously mentioned food plant and outlets, the amounts of food refuse disposed of each year amounts to 64.8 kg per person. Also, 44.4 kg per person (calculated at a water content of 80%) of sewage sludge is produced using a dewatered sludge cake volume conversion from the housing estate. This household sewage treatment flow is of a [biological degradation] - [concentration] - [dewatering] format as shown in figure 2. One part of the dewatered sludge cake is converted to compost with the rest being incinerated. As shown in Table 3, the excess sludge has a water content of 99% and BOD_5 of 1200 mgO_2/l; the thickened sludge has a water content of 95% and a BOD_5 of 100 mgO_2/g-ds; and the dewatered sludge cake has a water content of 77.6% and a BOD_5 of 93 mgO_2/g-ds. Judging from the state (high water content, high organic concentration) of the organic wastes from households and the food industry, the necessity of composting and thermophilic oxic process methods can be recognized as elemental technology contributing to their circulation.

3.2 The significance of essential technology for a recycling system

(A) The roles of "composting" and "thermophilic oxic process" in the system arrangement

The composting method is a core technology when the regional circulation system involving the agricultural industry is considered, with the biological organic solid wastes such as livestock feces and food refuse being targeted.

Compost is a fertilizer and has been produced by farmers from the past. There is a high proportion of easily decomposable organic matter in food wastes and sewage and if these are directly used in large amounts on agricultural land, they are quickly decomposed leading to a lack of oxygen in the soil layer. As this is a cause of germination and root decay, easily degraded organic matter, which is in an unstable state, should be stabilized by composting before application to farmland. However, as the amount of required fertilizer fluctuates seasonally, it is expected that there would be increases in production costs due to stoppages at the composting facility and decreased operating rates. Furthermore, the re-usage route of organic waste materials is not necessarily always maintained. Thus in the periods when some other method is required besides compost in order to decompose and reduce in volume of organic matter.

(B) Characteristics of the thermophilic oxic process

The principle of the thermophilic oxic process is the decomposition of organic material by microorganisms. As this basic mechanism is similar to that of the composting, the same facilities can be utilized for both processes. However, the differences between the two lies in the operating conditions. In the thermophilic oxic process, firstly the highly concentrated organic wastes are added with the existence of medium that it is able to maintain the water content in the device, and then a reaction is carried out by thermophilic bacteria, which decompose organic matter quickly under aerobic conditions. The medium inside fulfils the function of maintaining the bacteria and adjusting the water content and also maintaining oxygen level. In this way, the highly concentrated organic wastewater is absorbed into the medium and the water content can be controlled. Thus the thermophilic oxic process has been proved as an effective solution for the materials with high organic and high water content which make trouble in conventional composting technology.

The thermophilic oxic process was originally researched by Mori et al. as a method to treat wastewater containing high concentrations of organic material (Mori *et al.*, 1993). This method was used first of all on the treatment of the waste water from bean-jam processing and then for the treatment of Shochu waste liquid (Liu *et al.*, 1992; Liu and Mori, 1993). Furthermore, Liu et al. devised a way of supplementing the energy lacking during the treatment by the thermophilic oxic process by adding waste cooking oil, which is a high calorie material and carried out the treatment of swine waste (Liu *et al.*, 1994). Further still, Zhu et al. thermophilic aerobically decomposed the organic residuals from sewage filtration by using cedar chips as supporting medium and achieved an 85% BOD degradation rate by adding rice bran as an energy source (Zhu and Mori, 1995). From these results, the characteristics of the thermophilic oxic process are the biological reaction of high calorific organic material by aerobic thermophilic bacteria and the evaporation of the water content by using the heat generated in that process. It is rather simple and low-cost comparing with other treatment methods. We have also performed the treatment of sewage sludge by the thermophilic oxic process (Yang *et al.*, 1997) and from those experimental results, the ratio of the calorific value and the latent heat of evaporation of water in the raw material was found to be an extremely important factor for the thermophilic oxic process. In short, highly concentrated organic matter is completely decomposed by thermophilic bacteria and as all the water in the waste material is simultaneously evaporated off. The energy that the organic material added into the device contains as well as the balance with the latent heat of evaporation of the water containing in the raw material is indispensable conditions for the stable progress of the reaction.

3.3 Models for the "composting" and the "thermophilic oxic process"

In order to select the suitable treatment and recycling technology corresponding to the state, structure and components of the organic matter for constructing a recycle system shown in Figure 1, a mathematical model of each of the processes is required.

The above-mentioned composting and thermophilic oxic process are biological reactions and the special feature of both processes is the generation of heat. The heat generated as the decomposition of the organic matter in the raw material accelerates the reaction, and it again results in the acceleration of the heat generation. Accordingly, the amount of calorie contained in the raw material is one of the important indices in determining whether it can be treated by the composting or the thermophilic oxic process.

On the other hand, during the composting, the water content is the most significant factor affecting the reaction rate with water content control being of paramount importance for the production of good quality compost. Accordingly, the Hs/Hw ratio (Heat possessed by raw material/Evaporation heat) of the raw material has been adopted as the main operation variable to distinguish the composting and thermophilic oxic process.

The basic equations necessary for the energy balance analysis of batch type composting and thermophilic oxic process are shown in the following table.

Items	Equation
Decomposition heat of the organic material (kcal)	⊿Qr=hs・⊿S
Heat quantity needed for the temperature increase (kcal)	⊿Qm=Cm・M・⊿T
Heat quantity for synthesizing cells (kcal)	⊿Qx=hs・⊿X
Latent heat of evaporation of water (kcal)	⊿Qwl=hw・⊿W
Heat quantity that water contains (kcal)	⊿Qs=Cw・(T-Ta)・⊿W
Sensible heat removed by aeration (kcal)	⊿Qa=q・Ca・(T-Ta)・⊿t
Heat loss from the fermentation tank (kcal)	⊿Ql=K・F・(T-Ta)・⊿t

Abbreviations : hs = calorie possessed (kcal/kg) per dried unit of organic material; Cm = Specific heat [cal/(kg・℃)] of reaction materials; Cw = Specific heat [cal/(kg・℃)] of water; hw = Latent heat of evaporation of water (kcal/kg); Ca = Specific heat of air [cal/(m^3・℃)]; S = Mass of organic material (kg); M = Mass of reaction material (kg); X = Mass of microorganisms (kg); W = Amount of water in the reaction material (kg); T = temperature inside reaction vessel (℃); Ta = Atmospheric temperature (℃); q = aeration rate (m^3/h); K = Heat loss coefficient of the reaction vessel [kcal/(m^2 ・h・℃)]; F = Total surface area (m^2) of the reaction vessel; t = reaction time (h).

The thermal balance of the total system is given by:

$$\triangle Qr = \triangle Qm + \triangle Qx + \triangle Qwl + \triangle Qs + \triangle Qa + \triangle Ql \quad (1)$$

Also, if the actual yield of bacteria in the reaction process is Y;

$$\Delta X = -Y \Delta S \quad (2)$$

The total mass in the reaction vessel is the sum of the total organic mass (S), the total bacterial mass (X), the total water content (W) and the total mass of non-decomposable material (U).

$$M=S+X+W+U \quad (3)$$

These basic equations are common to both the composting and thermophilic oxic process. In order to differentiate between both methods, the following has been assumed.

(A) For composting :

The initial bacterial mass is almost zero.

$$X_0=0 \quad (4)$$

After 1 reaction cycle, all the organic material has been completely consumed.

$$S=0 \quad (5)$$

The calorific value of the raw material and the heat generated from biological reaction are assumed to be almost equal. Integration by inserting equations (2)((5) into equation (1) gives the following for equation (1):

$$\frac{Hs}{Hw} = \frac{hsS}{hwW} = \frac{hs(1+R)}{hwWm} * \frac{(1-Wt)\{Cc(T-T_0)+H'\}+(Wi-Wt)\{Cw(T-Ta)+hw\}}{(1-Y)\{hs(1-Wt)-hwWt-Cw(T-Ta)Wt\}} \quad (6)$$

Displayed as:

$$H' = (Qa + Ql) / Mi \quad (7)$$

The return ratio $R = \frac{W_m - W_i}{W_i - W_t}$ where Wm, Wi and Wt are the water content of the added raw material, the water content of the mixture at the start of the reaction and the water content of the product, respectively.

(B) For the thermophilic oxic process

As the amount of generated excess sludge in one cycle is extremely small, $\Delta X = 0$. Also, all the organic material is presumed to be used up during the reaction.

The Hs/Hw ratio of the calorific value of the raw material added into the reaction tank and the latent heat of evaporation of water in the raw material is shown as:

$$\frac{Hs}{Hw} = \frac{hsS}{hwW} = \frac{rCc\Delta T + Wm\{Cw(T - Ta) + hw\} + (Qa + Ql)/Mm}{hwWm} \quad (8)$$

Thus, the inlet ratio $r = \frac{Mi}{Mm}$ where Mm is the mass of the added raw material and Mi is the total mass at the start of the reaction.

3.4 Experiment and data analysis

The reactor was made of stainless cylindrical container with an effective volume of 70 L and outside of the reactor was surrounded by a polystyrene insulation. Air was supplied from the bottom of the reactor by an air pump. A perforated plate was placed at the bottom of the reactor to support the medium of cedar chips and distribute air. Temperature was monitored by using a thermocouple inserted into the medium at the center of the reactor, and was recorded automatically by computer. The weight change of the mixture was monitored continuously by setting the reactor on the electric scale.

The same apparatus was used for both the composting and thermophilic oxic process test. The composting test was conducted on a batch cycle of 7 days. During the experiment of thermophilic oxic process, addition of sewage sludge and waste food oil was carried out each two day's interval. They were completely mixed with medium by a mixer. The mixture sample was taken before and after addition to determine the moisture content and volatile matter.

Using the experimental data from the composting and thermophilic oxic process, the results calculated using equations (6) and (8) are shown in Figure 3. From this figure:

① In the case of composting, in order for the reaction to proceed suitably and to produce a product with water content of 30%, it is necessary for the Hs/Hw ratio of the raw material to be at least 1.5 at a raw material water content of 60%. And the Hs/Hw ratio to be at least 1.8 at a raw material water content of 70%.

② For the thermophilic oxic process, the Hs/Hw ratio of the raw material needs to be greater than 2.2 to fully decompose the organic matter of the raw material and to fully evaporate the water of the raw material. However, if the raw material water content is greater than 80%, it is understood that the Hs/Hw ratio of the raw material may suffice at being greater than 1.7.

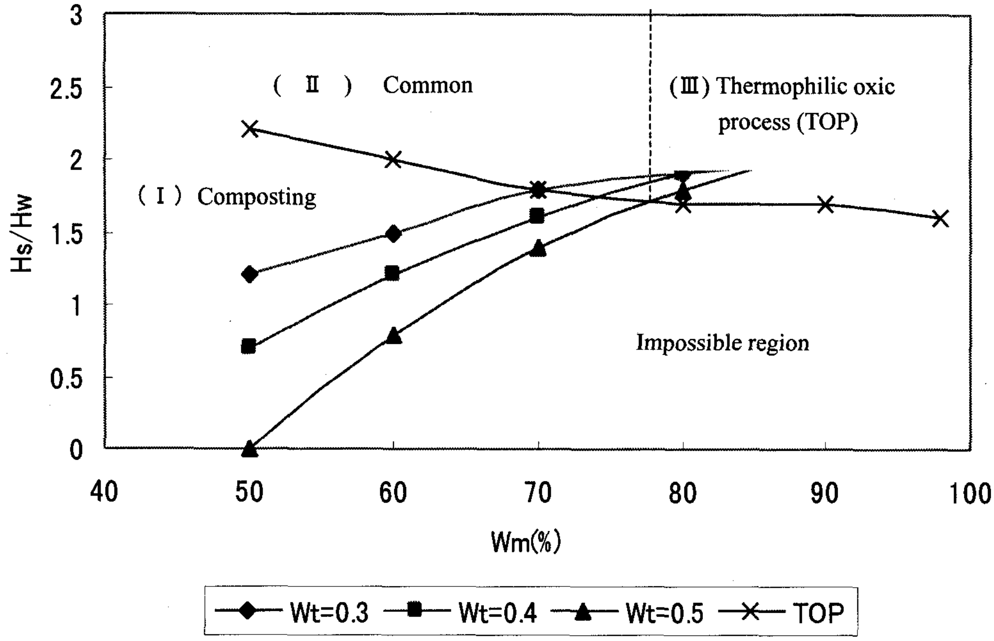

Figure 3 The relation of Hs/Hw and water content of raw material during composting and thermophilic oxic process

In Figure 3, three regions have been identified.

① With raw material having a water content of 50～70%, if the Hs/Hw ratio is within the region I, composting is possible but the thermophilic oxic process is problematic.

② In region II where the raw material water content is 50～78% and the Hs/Hw ratio is greater than 1.9, both composting and the thermophilic oxic process are possible.

③ With raw material having a water content of 80% in region III, the limits of the fermentation conditions for composting have been exceeded and the reaction can not apparently proceed (Fujita, 1995). In such a case, it is understood that the thermophilic oxic process is the suitable treatment method.

4. Establishment of a recycling process for typical organic matters

There is a variety of organic material in a recycling system and it is necessary to select a variety of circulation passes to determine whether to produce fertilizer from the organic material or to decompose it completely and use the small amount of residuals as a soil improvement agent. Accordingly, the suitable recycling process was evaluated for typical material.

4.1 Organic material from food sources

According to the aforementioned examination results of a food plant, the amount of bean curd residual generated annually is 6,500 tons with a generation rate of 76.5% respective to the amount of product. Its dry contents of protein is 25%, lipids 19%, carbohydrates 51% and ash 4%. The nutrient content is high with it being effectively used as a food source, as feed for livestock or fertilizer for crops.

The organic wastes from food processing plant had been recycled as feed before 70's in Japan. However, this circulation was broken due to various reasons. The domestic fact is the high cost of transportation, etc. Also the input feed become relatively cheep due to the exchange rate, corn market in Chicago, etc. (Kusube et al., 1998). The feed for livestock has been replaced by imported feed and the use of bean curd residual has decreased. Furthermore, changes in dietary habits have also caused sharp reductions in the food used. As the demand for bean curd residual has decreased in this way, the introduction of a treatment and recycling process have become necessary. As shown in Table 2, the water content of bean curd residual is 81.1% and as it is difficult to use as a raw material for composting, a decision of whether to add a bulking material or to dehydrate it is necessary. Also, as the nitrogen and protein contents are high, combination with materials having a high carbon proportion is effective. Thus the water content of the raw material falls below 80% and the Hs/Hw ratio increases above 1.9 entering region II in Figure 3. However there are problems as the water content of the bean curd residual is high, storage is difficult because it is perishable, there are many small-scale producers dispersed locally and the products are difficult to be turned into compost quickly. Judging from these conditions, on-site treatment at each production plant using a thermophilic oxic process device is largely effective.

4.2 Organic material from household sources

As for household waste, the amount of sewage sludge generated is increasing in connection with the widespread use of sewage networks. When sewage sludge is returned to farmland by composting, it is important to obtain a balance between the supply and demand of that compost. It is also necessary to implement policies for seasonal changes of demanding compost. The thermophilic oxic process proposed by the authors is one efficient way.

As shown in Table 3, the water content of sewage sludge is extremely high and, using the energy balance and mass balance calculations, the amount of heat generated from the decomposition of sewage sludge alone is insufficient due to the requirement of a large amount of water evaporation. As a result, it was thought that the addition of another heat resource is required. Waste cooking oil collected from households was used as an energy resource in an experiment. In Japan, it is estimated that the total amount of waste cooking oil produced every year is 370,000～460,000 tons or 2.8～3.5 kg per person each year. The BOD of waste cooking oil is extremely highly concentrated and the disposal in wastewater of household cooking oil leads to dramatic increases in the pollution of wastewater. Thus the development of a treatment method for waste cooking oil is desirable. Furthermore, the amount of waste frying oil generated from the aforementioned food plant was high. From the viewpoints of reductions in environmental load caused by waste cooking oil, the effective re-use of resources and the decreases in amount of food refuse, it is thought that waste cooking oil can be used as a bio-fuel. The thermophilic oxic process almost completely treats organic material by the activation of bacteria that use organic wastes as energy sources and as is it a method that evaporates the water, it is advantageous from the viewpoint of low cost running.

The individual treatment of food by-products and household organic wastes is possible by the application of the thermophilic oxic process. Furthermore, by combining the organic waste from food sources (with low water contents, and where the organic concentration is high etc.) with the household organic wastes (sewage sludge and food refuse, with high water content etc.) in a regional recycling system, high efficiency, low cost treatment is possible.

5. Summary and future development

In order to select either "composting" or "thermophilic oxic process" in accordance with the quality and quantity of organic material generated in a region, it is necessary to understand those mechanisms and construct mathematical models. In this research, the "Hs/Hw Ratio" of organic material is proposed as an important design factor allowing the selection of the treatment process. It should be noted that the thermophilic oxic process, which is a newly proposed, is simple and probably is low cost though not quantitatively evaluated yet but because of simple design and also depending on the almost energy free microbiological activity. It is considered that the thermophilic oxic process can be used as a decomposition method for organic material in the periods when compost is not in demand. Thus it is allowing the understanding of the characteristics of these kinds of elemental technology and the establishment of recycling systems. However, the organic matter recycling system should not be thought of only in terms of treatment ability but evaluations of the operation cost, consumption of energy and amount of CO_2 produced need to be performed. These will be addressed in future studies.

Furthermore, we believe it is also necessary to increase the diversity of these systems by incorporating a variety of processes such as other biological treatment methods (thermophilic anaerobic process etc.) and energy conversion methods (methane fermentation etc.) in addition to composting and the thermophilic oxic process as recycling technical elements. Ultimately, a complete regional resource recycling system that is capable of effectively utilizing by-products from various sectors such as the food industry, distribution processes, agriculture and livestock industry could be formed thus achieving a true circulatory society harmonizing with the natural eco-system. This research has been undertaken as a first step with these ultimate aims.

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