Case Studies

An LCA Study on Sludge Retreatment Processes in Japan

Advantages of Concurrently Treating Kitchen Wastes, Night Soil, and Night Soil Digestion Sludge, Using High-speed Methane Fermentation System

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Abstract. The majority of night soil (human excrements) is source separated from other sewage water and treated at night soil treatment plants in Japan. Efforts have been made to achieve material recovery from this organic mass, together with other organic wastes such as kitchen wastes and manure, by expanding the functions at night soil treatment plants. These facilities with expanded function are called 'sludge retreatment centers', which are promoted by the Japanese Ministry of Health and Welfare. Potential environmental impacts of sludge retreatment using two presently available systems in Japan are analyzed for comparison. Systems compared are: 1) Mebius system, a high-speed fermentation process with methane gas recovery and compost production and 2) a comparable system with a basic composting process. The functional unit for this study is concurrent treatment of 40 t/d of kitchen waste, 40 m^3/d of night soil, and 60 m^3/d of private sewage treatment tank sludge. Impact assessment on Global Warming (IPCC 1996, 20 yrs.), Acidification Potential (De Leeuv – AP), Eutrophication Potential (De Leeuv – EP) and Resource Index (Fava/SETAC & Heijungs) all indicated that sludge retreatment with Mebius system provides a better environmental performance. The main reasons are: 1) production of power using recovered methane and 2) reduction of sludge volume by digestion, which leads to reduction of fuel required for sludge drying. The collection and treatment of night soil and kitchen wastes involves many economic and social factors. Therefore, more studies with different functional units on these systems should be made to obtain a more complete picture that can be used for decision-making processes. The results of this study can be used as a starting point.

Keywords: Compost; fertilizer; LCA case study; Japan; material recovery; methane fermentation; night soil treatment; organic wastes; sludge retreatment

Introduction

Before chemical fertilizers became widely available in the 1940's, night soil (raw human excrements) was commonly used to fertilize agricultural fields in Japan. Each household stored it as a valuable resource. This commonly practiced source separation and temporary storage later led to the unique development of treatment plants for night soil and private sewage treatment tank digestion sludge (PSTT sludge), the latter being from modern, community-wide holding tanks with an aerobic or anaerobic digester [1].

The 1996 planning figure for the volume processed at night soil treatment plants was 33,750,000 m^3 in total [2]. Partial funding for the construction of these plants may be obtained from the 'National Waste Treatment Fund' of Japan only when the following conditions are met: 1) the plants must have some type of material recycle process incorporated; 2) additional organic wastes besides night soil and PSTT sludge must be accepted by the plant for processing [3]. The night soil treatment facilities that meet these new requirements are defined as 'sludge recycling centers'.

This paper presents results of the first comparative LCA study on two main types of sludge retreatment systems that are currently available in Japan. One employs a high-speed methane fermentation process for material recovery. Methane gas and digestion sludge, which can be used as compost, are being recovered in this system. The second type of the sludge retreatment system employs a basic composting process as its material recovery process. A paddle-type compost system is chosen to represent basic composting systems in this paper.

1 Methodological Approach

LCA principles and the framework defined in ISO14040 were generally followed. However, the study did not aim at compliance with all requirements laid down in this standard particularly for comparative assertions. This is for example true for a critical review. A critical review was not conducted since the study was not meant for publication but rather for internal purposes of the commissioner. Findings presented in this paper are therefore not suitable for making comparative assertions as defined in ISO14040. GaBi3 LCA software and database [4], developed by IKP and PE Product Engineering GmbH, were used as the assessment tool and source of data for ancillary processes. Key process parameters are obtained from design calculations. Regulation standards were used as emission values where other sources were not available.

2 Goal and Scope of the Study

The goal of this study is to quantify the potential environmental performance of two different types of sludge recycle systems available for comparison. Impact category indicators used are Global Warming Potential (IPCC [5] – 1996, GWP 20 yrs.), Acidification Potential (De Leeuv [6]), Eutrophication Potential (De Leeuv [6]), and Resource Index (Fava [7] /SETAC & Heijungs [8]). These were chosen to illustrate impacts from different points of view, such as air, water, nonrenewable resource, in both global and local scales.

The systems assessed are a Mebius system, with a high-speed methane fermentation process, and a comparable system with a composting process, which shall be called SC system (for sludge-to-compost) for convenience in this paper. These systems assessed in this paper are their representative models; the actual specifications vary for each plant, reflecting local needs. The two systems are divided into process groups and data were collected for each of these components. The original study that became the foundation of this paper was commissioned by Ebara Corporation for its internal use [9]. Ebara Corporation first introduced the core technology of Mebius, called the WAASA process – which was originally developed in Finland by Citec – in Japan in 1997. A few of the first plants were built this year. The target audience of the original study was Zero Emission Development Department staff of Ebara Corporation; while the target audience of this paper are scientists and practitioners of LCA.

The functional unit of this study is: 'concurrent treatment of 40 t/d of kitchen waste, 40 m^3/d of night soil, and 60 m^3/of PSTT sludge, while recovering valuable materials and energy, i.e. compost and electric power'. This composition of inputs was selected for the following three reasons: 1) This composition was used in a WAASA process trial run; therefore, some critical data were available, 2) It is possible to collect this amount from 2-3 small municipalities in the countryside (total population of approximately 78,000) in Japan and 3) This combination of input amounts generated the highest amount of electric power within the boundary defined by (1) and (2). It is known that the higher the ratio of kitchen wastes to the other inputs is, the higher the amount of power would be generated. However, the condition set by (2) above places limits on its feasibility.

The recovery of valuables is accounted for in the product systems using the system expansion approach, i.e. both systems shall produce equal amounts of the same valuables. Respective primary production chains shall be added to either system to ensure this. This procedure represents the potential of recovered valuables to displace other products. However, actual replacement of these goods may be restricted by market conditions, legislation or technical restrictions.

Composts: For this assessment, it is assumed that composts generated from the two systems replace the function of mineral fertilizers to supply plant nutrients. Urea (carbamine) and infused phosphate fertilizer have high domestic demands as fertilizer [10]. Therefore, the reference flow regarding compost generation is defined to be: 'effective (countable) nitrogen and phosphate that replaces 143.96 kg/d of urea (carbamine) and 555.16 kg/d of infused phosphate fertilizer'.

Methane gas: It is assumed that Methane gas generated from Mebius is only used for on-site power generation. The reference flow here is 18,839 MJ/d of electric power based on the power generation by Mebius.

Multi output allocation is generally done according to mass or energy content relations of product streams. Specific allocation decisions in the course of the project were not necessary. All cases of allocation occur in the ancillary chains for which predefined data from the GaBi 3 software database were employed. Due to the choice of the functional unit multi input allocation could be avoided. Systems are compared based on system expansion so that allocation with respect to product recovery could be avoided.

3 Description of Mebius System and SC System

Fig. 1 and 2 show the flow concept of the Mebius system and the SC system, respectively. Both systems consist of combinations of two major process groups: wastewater treatment processes and sludge/solid waste treatment processes with smaller process subgroups. Characteristic functions of the wastewater treatment processes are the same in both systems. The main difference between Mebius and SC systems are in their treatment of sludge/solid wastes which are described below.

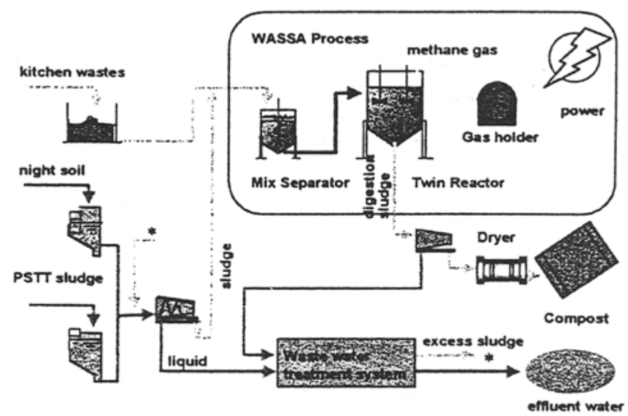

Fig. 1: Ebara Mebius System concept flow

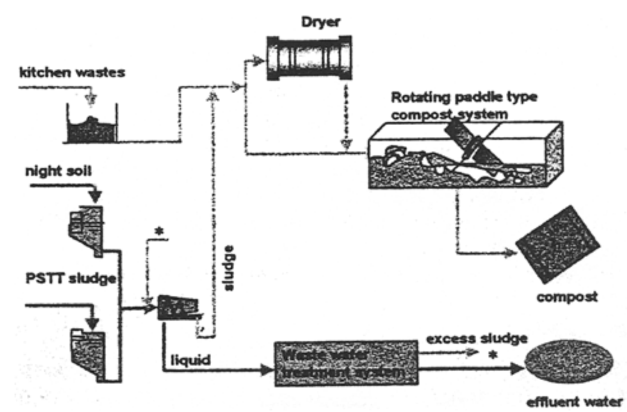

Fig. 2: SC System concept flow

Sludge/solid waste treatment in the Mebius System:

- After screening out indigestible wastes (e.g. plastics and metals), night soil and PSTT are dehydrated to 85% water content. It is mixed with kitchen wastes and excess sludge from water treatment in Mix Separator, where acid fermentation takes place. (Resident time = 1day) Heavy indigestible wastes (e.g. large pieces of vegetables) are separated out from the bottom of the reactor.

- Sludge from Mix Separator is sent to Twin Reactor, where it goes through methane fermentation. (Reactor temp. = 55°C; Resident time = 16 days) During the digestion, internal circulation and stirring of the sludge assures homogeneous reactions in the vessel. The reactor is sealed, thus there is no risk of methane emission.
- Methane gas generated via fermentation is collected in a tank. Electric power is generated using the methane-gas power generator. This power is used on site for plant operation.
- Digestion sludge obtained after methane fermentation is dehydrated to 75% moisture content, then dried by heavy fuel oil burner to be used as compost. Liquid from dehydration is sent to the water treatment process.

Sludge/solid waste treatment in the SC System:

- Kitchen wastes, after screening, is divided into 2 portions. Approximately 84% of the waste is first dried by the gas burner to 30% moisture content, then re-mixed with the other 16% (85% moisture content) and water treatment excess sludge for composting in a fermenter with paddle-type cutters. Complete composting process (primary fermentation and maturing) takes approximately 40 days.

Mebius and SC systems have the odorous treatment system that consists of bio-catalytic treatment, acid-base chemical treatment, and activated carbon treatment. However, in addition, a soil filter is added to the SC system to treat the odorous air generated in its composting system.

4 Results and Discussion

Global Warming Potential (IPCC [5], 1996 - GWP 20 yrs.): Fig. 3 shows the results of impact assessment on GWP (20 yrs.). The main factors contributing to the impact is usage of thermal energy from heavy fuel oil and of electric power at the plants.

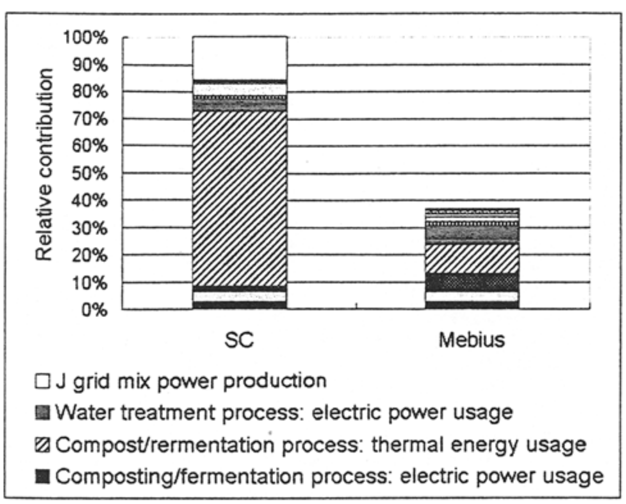

Fig. 3: Global Warming Potential (IPCC-1996, 20 yrs)

Overall, usage of thermal energy from heavy oil for sludge drying requirement is the decisive factor. Impact caused by sludge drying in SC system sizes approximately 64% against the total of this system, while total impact by the Mebius system is 37% against the SC system. The Mebius System uses approximately 0.230 m^3/h of heavy fuel oil for drying digested sludge, while SC System uses approximately 0.800 m^3/h for sludge drying before composting. Methane fermentation reduces approximately 46% of sludge mass. The amount of drying needed is reduced accordingly.

On site, Mebius system uses more electricity. The highest power consumer is the fermentation process, where sludge is continuously stirred and circulated for mixing. The next highest power consumer is pumps in the Mebius 'water treatment' system, which is 3.5 times as much as SC water treatment due to the amount of water that is to be treated (316 m^3/d, compared to 113 m^3/d). The 'deodorizing' process of SC system also takes a significant percentage of the overall electricity use because of the fans due to high air volume generated in the drying processes. However, on-site power generation provides an advantage, almost canceling out the impact by using electricity, to Mebius in this comparative study.

Acidification Potential (De Leeuv [6] - AP): Fig. 4 shows the result of AP impact assessment on the Mebius System and the SC System. The usage of heavy fuel oil to dry the sludge in the 'composting' system clearly dominates the cause of the impact. The total impact by Mebius is 39% of that by the SC system.

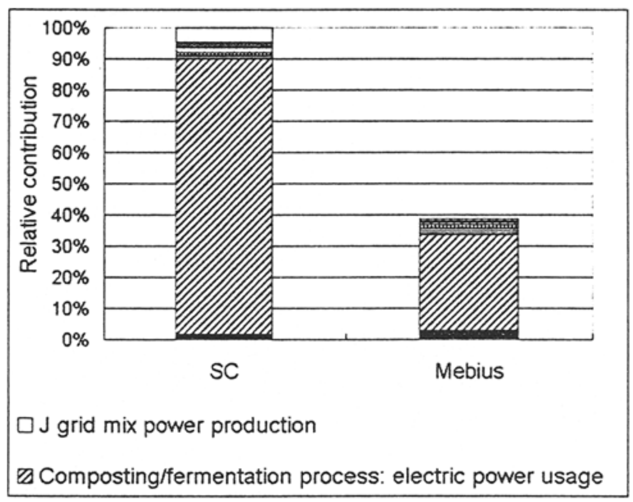

Fig. 4: Acidification Potential (De Leeuv)

Eutrophication Potential (De Leeuv [6] - EP): Fig. 5 shows the result of assessment on Eutrophication Potential (De Leeuv - EP). The greatest contribution factor comes from drying organic wastes in a kiln. This is due to the fact that emission standards are used up to the limit to calculate the emission, even within the combined exhaust volumes of the burner and the evaporated water. Evaporation of moisture produces a significant amount of vapor flux. In case of SC, approximately 20,000 Nm^3/h of dried gas is generated. This leads to a high amount of total emission per given time. The overall impact by Mebius is 73% of that by the SC system.

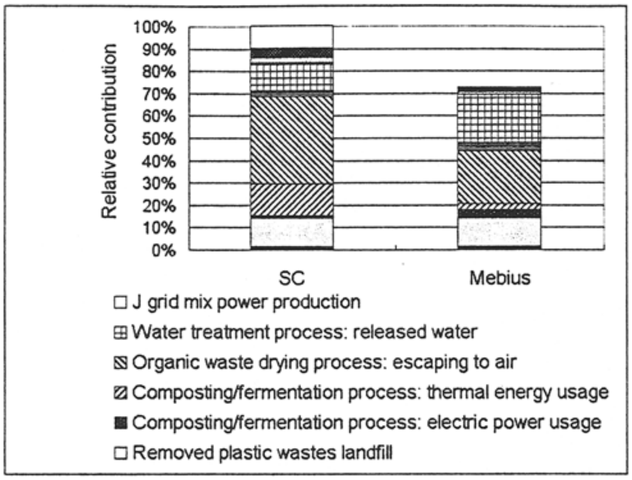

Fig. 5: Eutrophication Potential (De Leeuv)

Resource Index (Fava [7], SETAC & Heijungs [8]): Fig. 6 shows the results of a Resource Index assessment. The decisive impact elements are again heavy fuel oil sludge dryer and overall electricity usage.

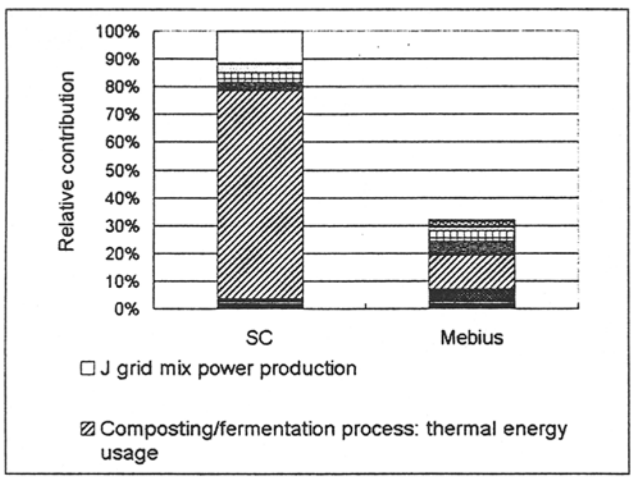

Fig. 6: Resource Index (Fava/SETAC & Heijungs)

5 Conclusion and Future Outlook

The results of this LCA study on the Mebius system and the SC System indicated that employment of the high-speed methane fermentation process in the sludge retreatment system makes it more environmentally friendly than using a standard composting process under the given functional unit. The main advantages of the Mebius system were: 1) sludge mass reduction via methane fermentation that leads to less usage of heavy oil fuel to dry the sludge; 2) electric power generation by recovered methane gas. Potential environmental impact of the Mebius system may be further reduced by: 1) utilization of soil filter for deodorizing odorous air, which would contribute in reducing the amount of wastewater to be treated, 2) if possible, reducing the electricity usage in fermentation reactors. Both power generation and mass reduction in the Mebius system are significantly affected by the quality of input waste mixture, which would vary considerably depending on the efficiency of the source separation of kitchen wastes in the local communities – this is the main disadvantage of the Mebius system. The amount of methane gas recovered must be above the minimum requirement set by the available standard gas-fired power generator for effective utilization of the system [11]. In the future, further LCA modeling of each system as a function of different input compositions should be performed in order to define the range in which the Mebius has an advantage over the other from an environmental point of view. It is also desired that more actual data be used in the analysis in place of design calculations and emission standards, once the data become available.

A production of compost did not present itself as a decisive factor in this comparative study. The main reasons were: 1) the only function of composts that was taken into account in this study was provision of nutrients to plants; 2) according to the design calculation, there was no significant difference in the total amount of nutrients in the compost. More detailed study on the nature and environmental impact of compost should be made in the future in order to obtain more accurate assessment regarding the effect of compost, and in order to obtain a more complete picture of sludge recycling.

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