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Sustainable Recycling of Livestock Wastes by Composting and Environmentally Friendly Control of Wastewater and Odors

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Abstract: Excess amounts of livestock wastes are excreted in limited area and cause pollution problems in Japan. Comparative studies on livestock waste management among EU (European Union), US (the United States of America) and Asia including Japan are surveyed. In Japan, livestock wastes are mostly separated into solid and liquid matter. Solid matter is converted into organic fertilizer by means of composting. Composting should be developed into the technology that has low emission, high-quality and low cost. Various odorous compounds are emitted from the process of livestock waste management. Odor emission from livestock farms should be mitigated to protect the local community. High-quality compost can be widely distributed to cropland to decrease expenditure of chemical fertilizer. Although liquid matter, namely wastewater or slurry, could be applied to cropland of livestock farms such as EU countries, most of Japanese farms do not have enough cropland to use liquid matter. Particularly pig farms have no area to spread wastewater, which should be purified to clean water in accordance with the criteria of water quality and could be discharged into public water area. The most desirable management of livestock wastes should involve sustainable recycling as compost and environmentally friendly control of odors and wastewater.

Key words: Livestock wastes, compost, wastewater, odor.

1. Introduction

Livestock provides us with delicious and nutritious products such as milk, beef, pork, egg, chicken meat, and their dishes. But the amount of livestock wastes excreted corresponds to several times as much as those of products (Fig. 1). Total amount of livestock wastes excreted in Japan is estimated at about 80 million tons per year. Many livestock raised in the limited areas of Japan result in the vast amount of accumulation of livestock wastes which cause serious pollution problems [1, 2]. In 1999, "The Law Concerning the Appropriate Treatment and Promotion of Utilization of Livestock Manure" has been enacted encouraging proper treatment and utilization. Results of the enforcement show that the management facilities of livestock waste in farm have extended at 100% by December 1, 2019 [3].

In Japan, most of solid matter in livestock waste is composted and applied to cropland as fertilizer. A part of dried solid matter from broiler litter is combusted to produce heat energy. Conversion process from waste into resources should be environmentally friendly and energy saving. Liquid matter is used for fertilizer or purified to discharge river and lake. Sustainable recycling of livestock wastes is desired in Japan which

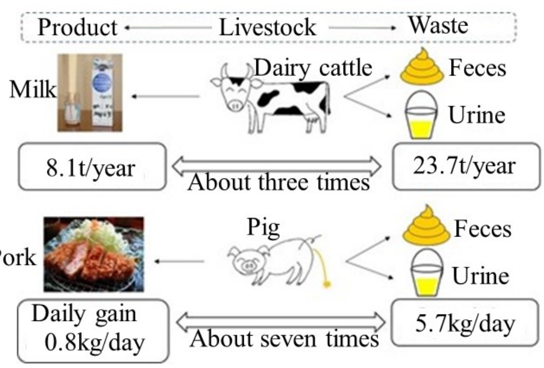

Fig. 1 Livestock wastes being several times as much as products per capita.

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lacks fertilizer and energy resources. It is also interesting to know the state of livestock waste management in foreign countries.

In this paper, comparative studies on livestock waste management among the EU (European Union), US (the United States of America), and Asian countries are surveyed and followed by Japanese challenge to manage livestock waste.

2. Outline of Livestock Wastes Management in EU, US and Asia

2.1 EU Countries

In EU, the limit application rate of nitrogen from livestock waste was fixed by Nitrate Directive adapted in 1991 [4]. The application rate, prohibition period of application, distance from water body, and storage tank volume needed for animal waste in selected EU countries are diverse according to national affairs as shown in Table 1.

Livestock farm should have enough area of field to be able to apply livestock waste at a rate of nitrogen shown in Table 1.

2.2 US

In US, ASABE (American Society of Agricultural and Biological Engineers) published 26 white papers concerning with livestock waste management [5]. Among them, the following five papers help us to know livestock waste management in US.

"Closures of earthen manure structures (No.11 of the white papers)" describes scientific guide about the closure of basin, holding pond and lagoons to manage livestock wastes appropriately.

"Legal structure governing animal waste management (No.13)" indicates CAFOs (Concentrated Animal Feeding Operations) as point sources of pollution. CAFOs are large-scale livestock operation feeding more than 1,000 cattle and excreting great amounts of wastes. There are about 19,500 CAFOs estimated in 2016.

"Manure management strategies and technologies (No.15)" explains the way to manage livestock wastes. Anaerobic lagoon, anaerobic digester, aerobic lagoon, chemical amendment, solid liquid separation, composting for solid, and wetland system for liquid are described in this paper. Effluent guideline is shown in CWA (Clean Water Act).

"Treatment lagoons for animal agriculture (No.21)" presents anaerobic lagoon as a standard method in US.

ASAE (American Society of Agricultural Engineers) (the former society of ASABE) Standards define a lagoon as a waste treatment impoundment in which manure is mixed with sufficient water to provide a high degree of dilution for the primary purpose of reducing pollution potential through biological activity.

"Odor mitigation for concentrated animal feeding operations: white paper and recommendation (No.25)" makes point of odor from CAFOs clear.

2.3 Vietnam

Current practices and existing technical approaches for waste management and treatment of the pig farms of Hanoi and its suburbs in Vietnam are shown in

Table 1 Livestock waste application to the field in selected EU countries [4].

	UK		Netherland	Denmark	Germany	France
Limit application rate of nitrogen (kg/ha)	Grass land	250	170	140	170	170
	Upland field	170				
Prohibition period of application	Grass land	Sep. 1~Nov. 1	Sep. 1~Jan. 31 at maximum	After harvesting	Nov. 15~Jan. 15	Sep. 1~Nov. 1
	Upland field	Oct. 1~Nov.1				
Distance from water body for application	More than 10 m		More than 5 m	More than 10 m	Control against surface runoff	Control against surface runoff
Storage tank volume needed	Corresponding to prohibition period for application		6 months storage	6~9 months storage	6 months storage	4 months storage

Table 2 Proportion of piggery waste treatment methods in some provinces of Vietnam [6].

Effluent management	Province (%)			
	Hung Yen	Ha Noi	Thai Binh	Bac Giang
Biogas	47.6	91.5	30	25
Compost	9.5	6.4	37	29
Used for plant	38.1	23.4	-	-
Directly discharge into environment	28.6	4.3	14	0
Directly to fish pond	52.4	17.0	-	-
Collection for sale	28.6	34.0	-	-
Stored	-	-	8	14

Table 3 Piggery wastewater treatment technology used in Philippines [7].

Size of farms		Number of pigs	Waste management
Commercial	Small	21 to 999 heads	46% lagoon; 40% settling ponds
	Medium	1,000 to 9,999 heads	62% lagoon; 7% biogas
	Large	10,000 heads and more	65% lagoon; 9% biogas
Backyard		20 heads or less	20% lagoon; 20% open pit; 13% septic tank

Table 4 Piggery wastewater treatment technology used in Thailand [8].

Treatment technology	Average
Pond system (2~10 ponds)	42%
Reception pond (1 pond only)	37%
Solid-liquid system + holding pond	7%
Biogas digester	6%
No treatment at all	7%

Table 2. Anaerobic digestion of piggery waste produces biogas and digested manure. Biogas is energy sources and digested manure is plant nutrient. Fishpond is also fertilized by livestock waste [6].

2.4 Philippines

Table 3 shows piggery wastewater treatment technology in Philippines. Lagoon system is widely used in Philippines farms. Biogas production connects with PEP (Philippines Energy Plan) which focuses sustainable energy through alternative fuels [7].

2.5 Thailand

Stabilization pond system is extended by the advantages of easy maintenance and operation, low capital cost, high removal efficiency of BOD (Biological Oxygen Demand) (80%), and modified flexibility of treatment system in Thailand (Table 4). But it needs large area to construct the pond system. Anaerobic condition in the bottom layer releases offensive odor such as hydrogen sulfide [8].

2.6 China

The Chinese government attaches great attention to the pollution problems of livestock waste. Some related laws and regulations have been enacted.

Among them, “Regulation on the Prevention and Control of Pollution from Large-scale Breeding of Livestock and Poultry” was enforced on January 1, 2014. The law presents the prevention of environmental pollution with control. Reasonable layout planning makes livestock farm divide into prohibited and restricted area of livestock keeping. Comprehensive utilization of livestock waste and organic fertilizer is recommended with tax incentive.

Fig. 2 shows treatment process for pig wastewater generally used in Chinese farms. Anaerobic digester is in the central position at which both energy (biogas) and fertilizer (slurry and compost) are produced. The treatment process consists of pretreatment by separation and sedimentation, anaerobic biochemical treatment by anaerobic digester, and aerobic biochemical treatment by composting [9].

Rapid increase in livestock production and enlargement of farm scale in China cause serious pollution problems. For example, 59% of total pollution load to Lake Tai, Jiangsu region, is caused by agricultural sector, mainly from livestock industry. Chinese government started to intensify pollution abatement from livestock industry.

2.7 Indonesia

Ministry of Agriculture, Indonesia enforced "Good Farming Practice" in 2011. Fig. 3 shows the example of Good Farming Practice for pig wastewater management in Indonesia [10].

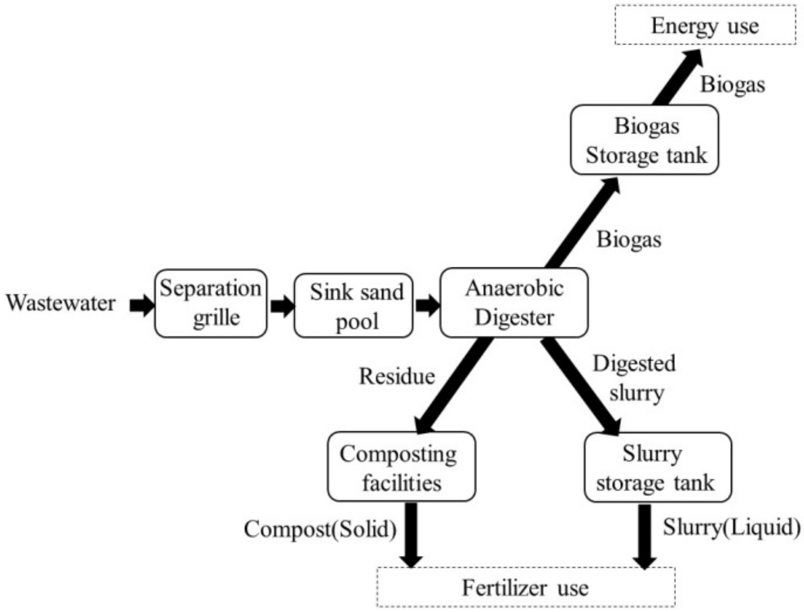

Fig. 2 Pig wastewater treatment process generally used in Chinese farms [9].

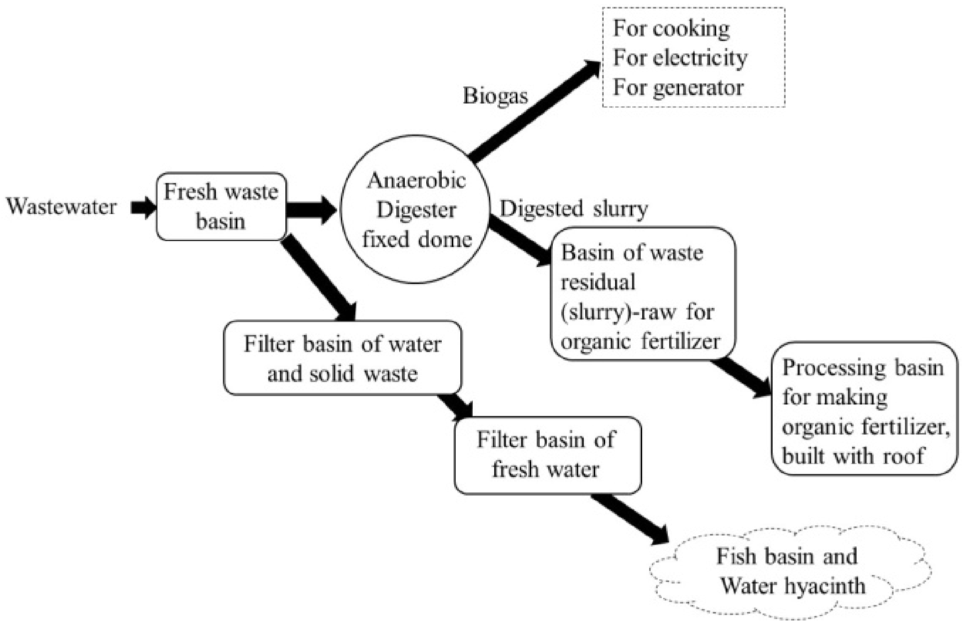

Fig. 3 Good farming practice for pig wastewater management in Indonesia [10].

3. Livestock Waste Management in Japan

The objectives of "The Law Concerning the Appropriate Treatment and Promotion of Utilization of Livestock Manure (1999)" promote appropriate treatment facilities for livestock waste management. They are achieved 100%, December 1, 2019 [3]. Present status of livestock waste management of each livestock is as follows [11].

3.1 Dairy Cattle Waste

As shown in Fig. 4, 30.9% of dairy cattle waste is separated into solid and liquid. Solid matter is mostly composted by piling method (87.3%). Liquid matter is mostly applied to cropland after the storage. More than the half of the solid-liquid mixture is turned into compost. Twenty five point seven percent (25.7%) of mixture is applied to cropland as liquid fertilizer (slurry). Methane fermentation is 5.9%.

3.2 Beef Cattle Waste

The mixture of feces, urine and bedding materials on the floor is scraped out as a solid matter which is easily composted. As shown in Fig. 5, the mixture is composted mostly by piling method (77.4%).

3.3 Pig Waste

Pig waste is separated into solid and liquid in house at a rate of 76.3% (Fig. 6). Solid matter is composted by piling (39.9%), open-type forced aeration (26.3%) and closed-type forced aeration (31.6%), respectively. As compared with cattle waste, pig waste prefers forced aeration method to piling one. Liquid matter is treated by wastewater treatment facilities to purify water quality and is discharged to river and other public water area (71.1%). Activated sludge process is applied to wastewater treatment with some improvements suitable for livestock industry.

Mixture of feces and urine with bedding materials is solid matter and is composted by piling (52.1%) and forced aeration method (23.2%). Mixture as slurry matter is treated by wastewater treatment facilities (11.7%) and methane fermentation (4.4%).

3.4 Layer Waste

Layer waste is composted by piling (35.3%), open-type forced aeration (29.0%) and closed-type forced aeration (23.0%), respectively (Fig. 7). This proportion looks like solid matter of pig waste (Fig. 6).

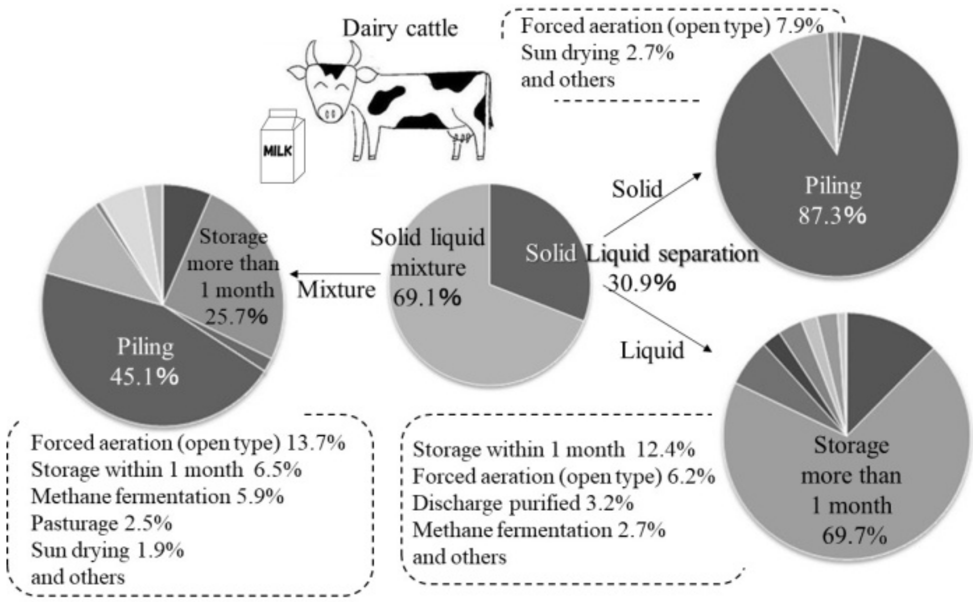

Fig. 4 Management of dairy cattle waste in Japan [11].

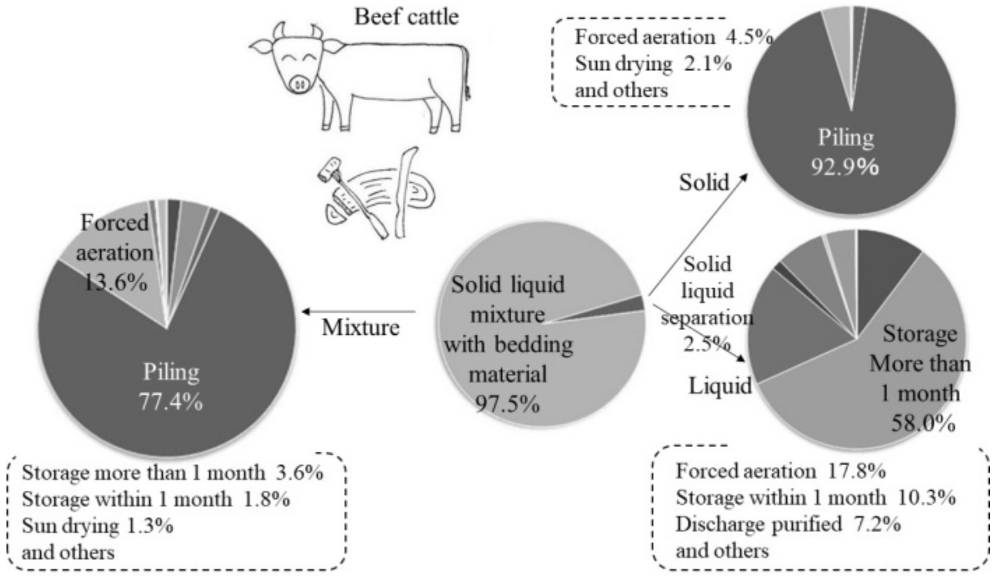

Fig. 5 Management of beef cattle waste in Japan [11].

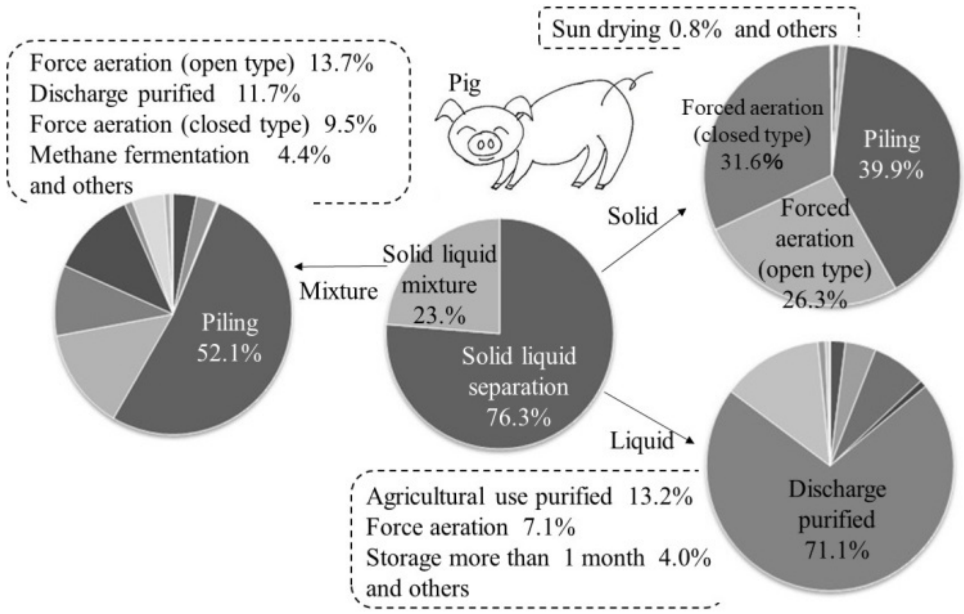

Fig. 6 Management of pig waste in Japan [11].

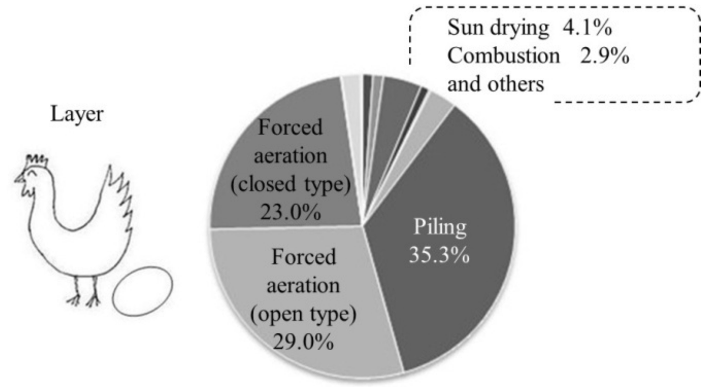

Fig. 7 Management of layer waste in Japan [11].

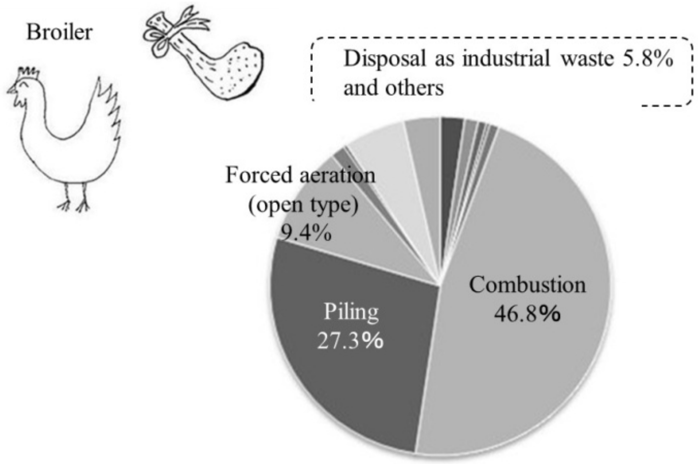

Fig. 8 Management of broiler waste in Japan [11].

3.5 Broiler Waste

As compared with layer waste, composting is small at 36.7%. On the other hand, combustion is large at 46.8% (Fig. 8). Broiler litter (broiler waste is sometimes called broiler litter) has been dried up to 35% moisture content and is suitable for burning. The combustion of broiler litter supplies energy to generate electricity and to boil water which is used for floor heating.

Consequently, composting, wastewater treatment and odor control are important subjects for livestock waste management in Japan.

4. Composting

The objectives in composting are to stabilize the biodegradable organic matter in raw livestock waste, to reduce offensive odor, to kill pathogenic organisms and to produce a uniform organic fertilizer suitable for the application to cropland [12]. Controlled conditions for microorganisms are important for composting process, to distinguish it from other natural biological decomposition such as rotting and putrefaction.

Moisture content of livestock waste at 75% to 85% is too high to supply oxygen to the microorganisms. Moisture control at around 65% by the addition of sawdust, rice hull, dried compost, and others is necessary to achieve composting process. The active degradation organic matter by the microorganisms under controlled conditions leads to heat production and moisture evaporation (Fig. 9). Solid decomposition at a rate of 20% to 40% [13] during composting process produces heat energy 18.8 MJ (4,500 kcal)/kg of solid decomposition. Moisture is evaporated by heat energy at a rate of 3.77 MJ (900 kcal)/kg of evaporation. It is comprehensively estimated by the many experimental data of livestock waste composting [14]. The livestock waste decreases by half in weight as the result of both solid decomposition and moisture evaporation during composting process (Fig. 9).

The high temperature higher than 60 °C contributes to the killing of weed seeds [15], and pathogenic microorganisms [16]. With occasional turning of the compost pile, the complete composting process requires a few months.

Various types of composting facilities to achieve favorable conditions for composting are available in Japanese farm [14]. The piling type (Fig. 10) is simple and easy in operation. Most of livestock farms use this type of facilities, especially for cattle farm. The compost is occasionally turned by shovel loader. The open elongated type with rotary turning device (Fig. 11), with scoop turning device (Fig. 12) and with screw turning device is also popular in pig and poultry farms. The enclosed vertical type (Fig. 13) is a kind of high-rate reactor of composting for pig and poultry wastes.

High-quality compost can be widely distributed to cropland (Fig. 14) to realize sustainable recycling of organic substances and plant nutrients. Composting

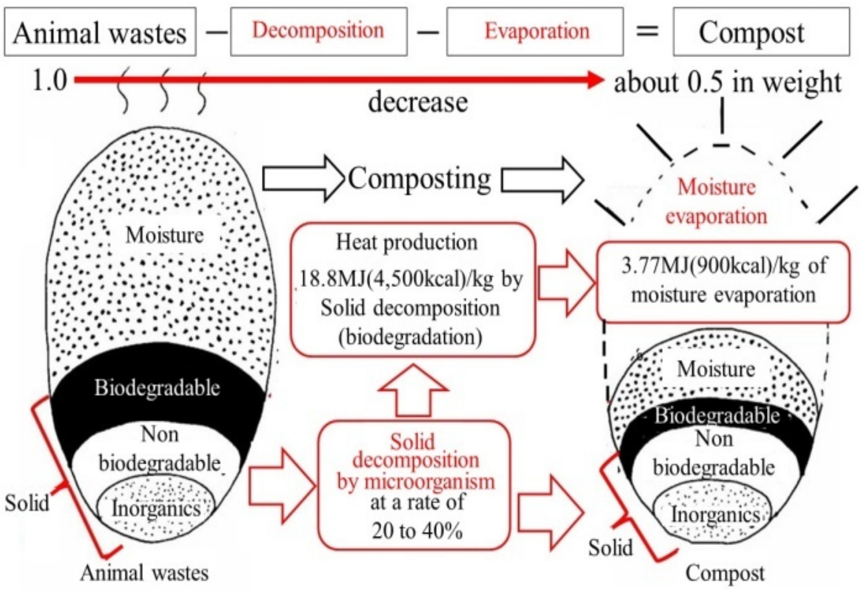

Fig. 9 Composting process of livestock waste with solid decomposition and moisture evaporation.

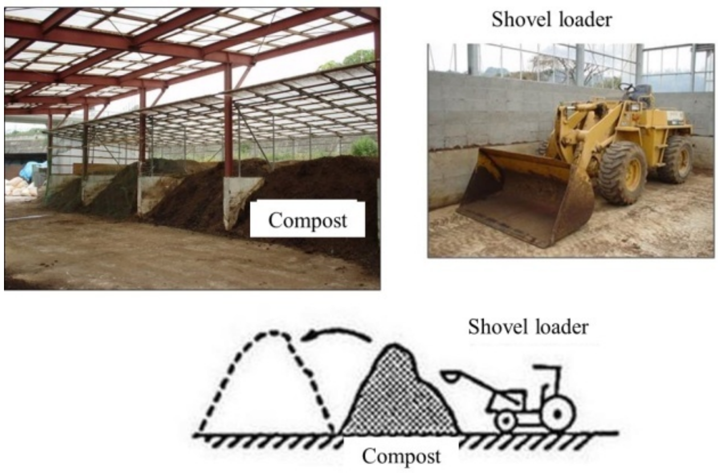

Fig. 10 Composting facilities: piling type.

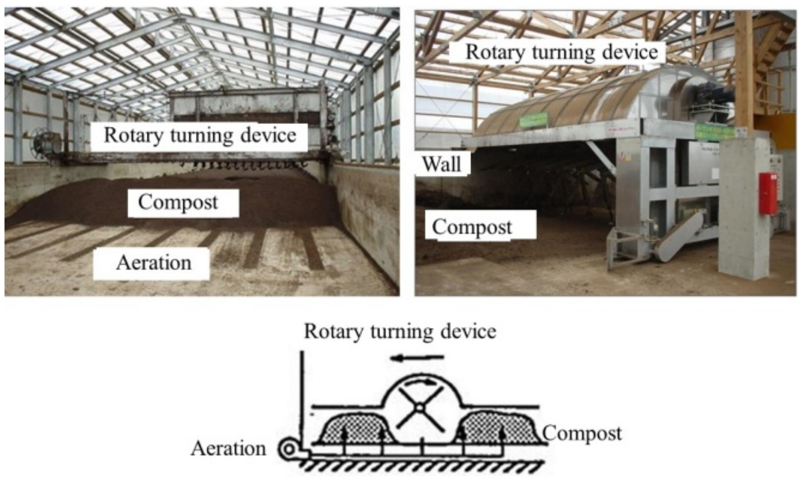

Fig. 11 Composting facilities: open type with rotary turning device.

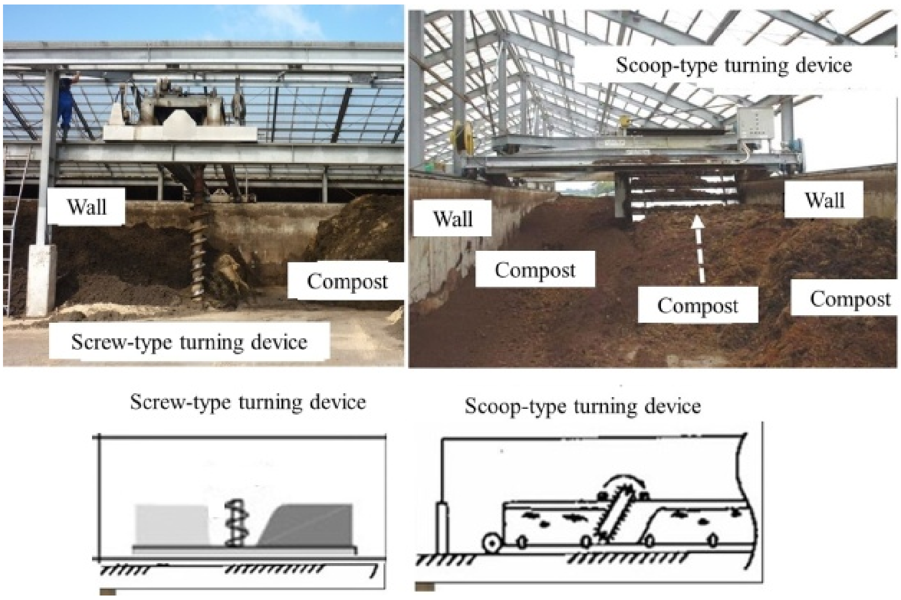

Fig. 12 Composting facilities: open type with scoop (right) and screw (left) turning device.

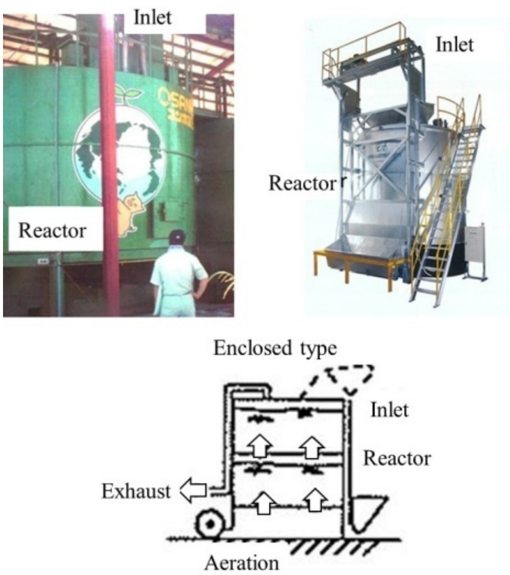

Fig. 13 Composting facilities: enclosed vertical type with turning and aeration.

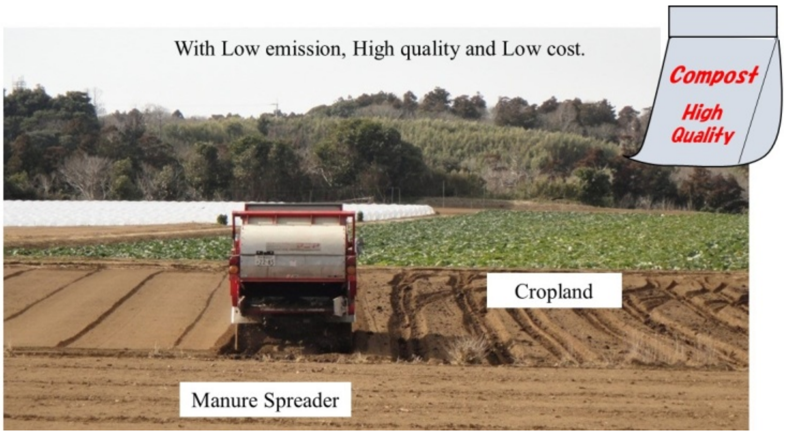

Fig. 14 Compost application to cropland by manure spreader.

should be developed into technology that has low emission [17], high quality [18], and low cost. The most desirable management of livestock wastes should involve sustainable recycling as compost and environmentally friendly control of wastewater and odors.

5. Wastewater Treatment

Table 5 shows effluent standards discharged from livestock farm to public water bodies in selected Asian countries presented at WEPA (Water Environmental Partnership Asia) Group Workshop on Pig Wastewater Management in Asia in 2017 [19]. They vary from country to country. For example, effluent standards of BOD vary from 60 to 250 mg/L.

In Japan, pig wastewater is mostly treated by activated sludge process (Fig. 15) to obtain clear water to secure strict regulation (Table 5). Activated sludge means an active population of microorganisms which decompose organic pollutants (BOD) in wastewater by use of dissolved oxygen.

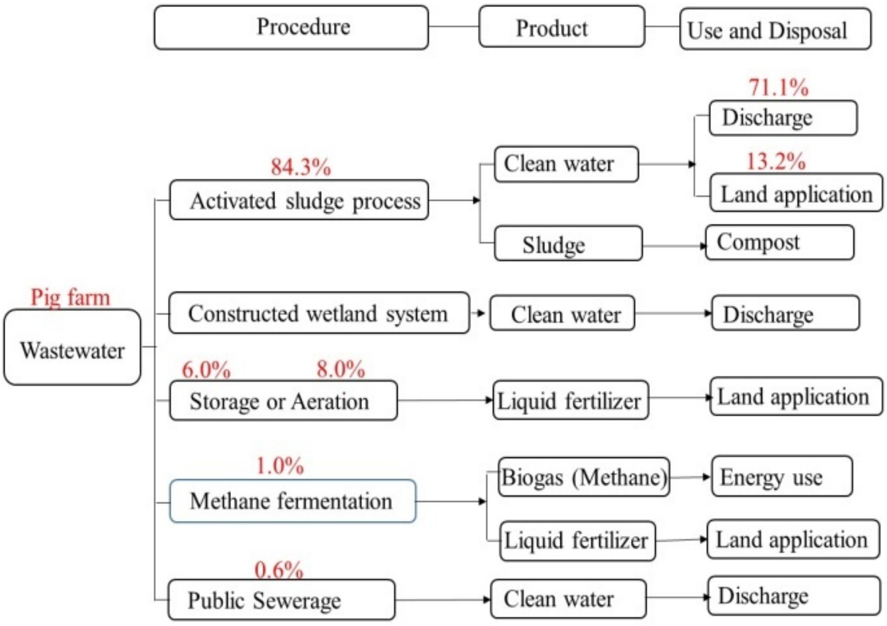

Fig. 15 Wastewater management in Japan (summarized by the data from Ref. [11]).

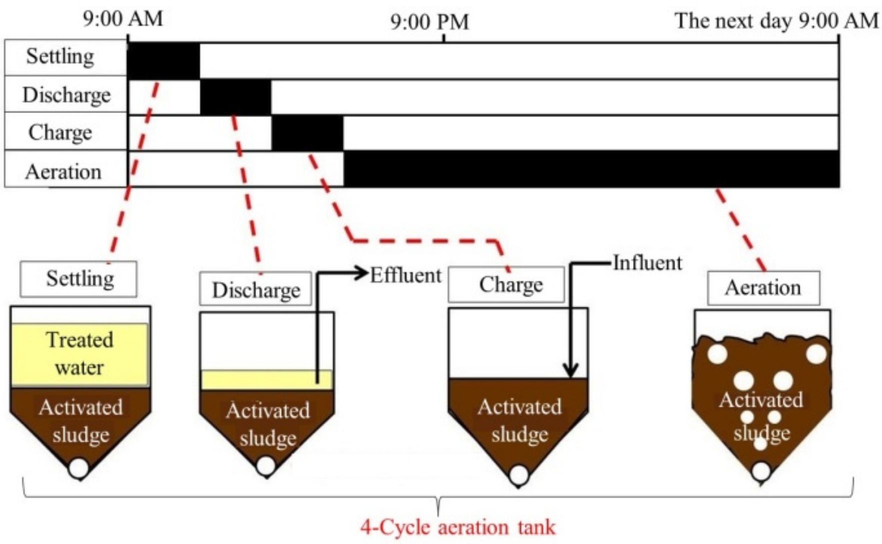

Fig. 16 Treatment schedule of activated sludge process; SBR (Sequence Batch Reactor) system.

Table 5 Effluent standard discharged from livestock farm to public water bodies in selected Asian countries [19].

Items	Unit	Countries								
		Cambodia	China	Indonesia	Japan	Philippines	Sri Lanka	Thailand		Vietnam
								A[d]	B[e]	
pH	-	5~9		6~9	5.8~8.6	6.0~9.5	5.5~9.0	5.5~9.0	5.5~9.0	5.5~9.0
BOD	mg/L	80	150	100	160	120	250	60	100	100
COD	mg/L	100	400	200	160[b]	200	400	300	400	300
Grease and oil	mg/L	15				15				
n-Hexane extracts	mg/L				30					
SS	mg/L	80	200	100	200	150	50	150	200	150
Cu	mg/L				3					
Zn	mg/L				2					
Fecal coliform	$/cm^3$				3,000 (total)	8				50
Ascaris eggs	/L		2.0							
T-N	mg/L				120			120	200	150
NH_3	mg/L		80	25 (NH_3-N)		7.5				
NO_3	mg/L									
Nitrates nitrogens[a]	mg/L	20			100[c]					
T-P	mg/L		8.0		16					
PO_4	mg/L	6.0								

(a) 0.4×NH_4-N+NO_2-N+NO_3-N; (b) COD_{Mn}; (c) Provisional standard of livestock farm is 500 mg/L until June 30, 2022; (d) A is large scale farm raising over 600 LU (Livestock Unit) of livestock. One LU means 500 kg of livestock in weight; (e) B is small and medium scale farm raising 6~600 LU.

Fig. 16 shows treatment schedule of activated sludge system. It consists of 4-cycle stages, namely settling, discharge, charge, and aeration. Firstly, in the settling stage, aeration stops, activated sludge settles, and treated water can be separated from activated sludge. In the discharge stage, treated water is discharged and influent is newly charged in the charge stage. In the aeration stage, activated sludge decomposes BOD by aeration until the next day. Fig. 17 shows the photo of aeration tank.

The schedule can be harmonized with pig raising. This system is called as SBR, and popular in pig wastewater treatment in Japan.

Conventional activated sludge process (Fig. 18) is also used in livestock wastewater. As for livestock wastewater, extended aeration process modified with longer retention time is popular. It is stable in operation for livestock farm.

MBR (Membrane Bioreactor) is recently popular using micropore membrane in place of settling tank [20]. Advanced treatment of nitrogen is required to comply with the regulations of nitrates nitrogens (Table 5). Nitrates nitrogens means total amount of 0.4×NH_4-N+NO_2-N+NO_3-N. Various denitrification processes [20] and anammox reaction [21] are applied to livestock wastewater which is rich in nitrogen and low in BOD/N ratio.

Constructed wetland system has its advantage of being easy to maintain. The performance is evaluated by pig wastewater [22].

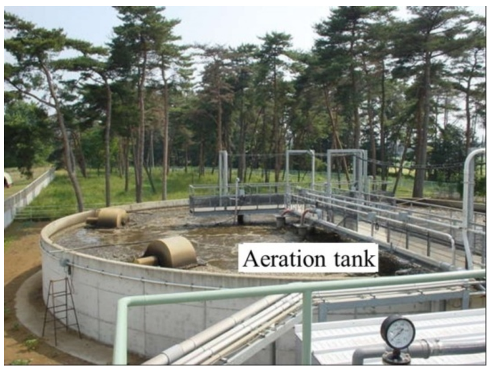

Fig. 17 SBR system for livestock wastewater.

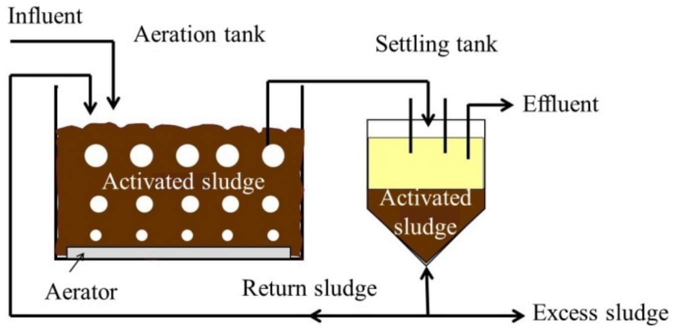

Fig. 18 Conventional activated sludge process.

6. Odor Control

Odor problems constitute more than half of the complains about livestock farming in Japan [3]. They are urgent issues to be solved. To feel that livestock farming smells bad is mainly due to the odorous compounds generated from livestock waste. Most of the odorous compounds, volatile fatty acids, hydrogen sulfide and so on, are generated from livestock waste under anaerobic conditions as shown in Fig. 19. Volatile fatty acids are accumulated under anaerobic condition, on the contrary they are decomposed under aerobic condition during composting [23]. Volatile fatty acids are rarely detected during activated sludge process of livestock wastewater [20].

Ammonia is generated under both anaerobic and aerobic conditions as the decomposition of nitrogenous compounds contained in livestock wastes proceeds. In the initial stage of composting, vast amount of ammonia, sometimes several thousand ppm, is emitted [24] and is not fully oxidized to no-smell form, nitrate (Fig. 19). Ammonia reduction is based on the characteristics of deodorization, mainly on the high solubility and microbiological decomposability (Table 6).

Ammonia in exhaust air from composting should be removed by deodorizing device. Deodorizing device packed with RW (Rock Wool) medium (Fig. 20) is usually applied to composting facilities. Ammonia is dissolved in surface water of RW medium at high solubility and is decomposed by microorganism living in the surface water. Exhaust containing about 300 ppm of ammonia can be deodorized to 0 ppm [14].

Comprehensive measures for odor control are developed as BMP (Best Management Practices) for odor control in Japan [25]. Each BMP to do in livestock house, waste management, compost application to cropland, and deodorizing facilities is enumerated.

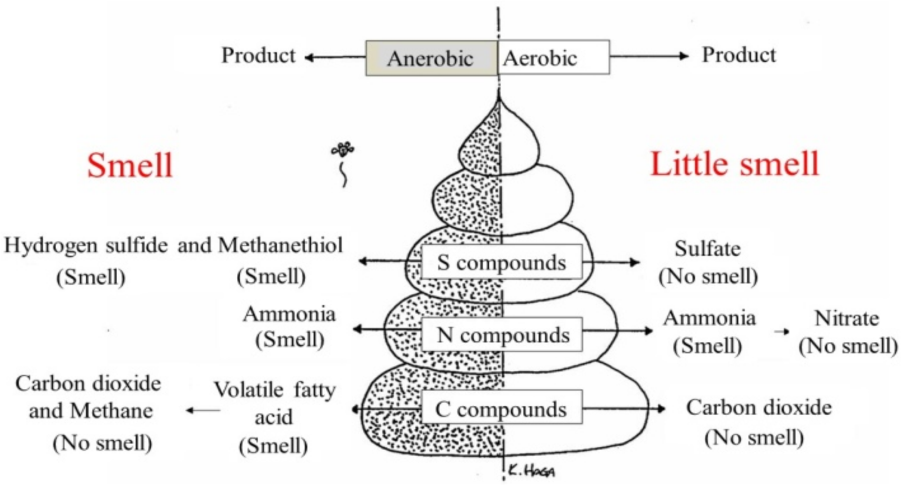

Fig. 19 Odorous compounds from aerobic and anaerobic decomposition process of livestock wastes.

Table 6 Characteristics of odorous compounds from livestock waste and their deodorization [25].

Odorous compounds	Deodorization	Solubility 20 °C (mL/mL water)	Acid or alkaline	Ozone	Activated carbon	Microorganism
Nitrogenous	Ammonia	702	Alkaline, efficiently absorbed in acid solution	Hardly decomposable	Non-absorbable	Nitrification by nitrifying bacteria assimilation by bacteria
Sulfurous	Hydrogen sulfide	2.6	Weak acid	Decomposable	Absorbable	Oxidation by sulfur oxidizing bacteria, photosynthetic bacteria etc.
	Methyl mercaptan	11				
	Dimethyl sulfide	7.9	Neutral			
	Dimethyl disulfide	0.6				
Volatile fatty acid	Propionic acid	302 (miscible)	Acid, efficiently absorbed in alkaline solution	Hardly decomposable	Absorbable	Decomposition by aerobic microorganism. Conversion to CH_4 and CO_2 by methane bacteria
	n-Butyric acid	14 (miscible)				
	n-Valeric acid	5.3				
	Iso-Valeric acid	5.3				

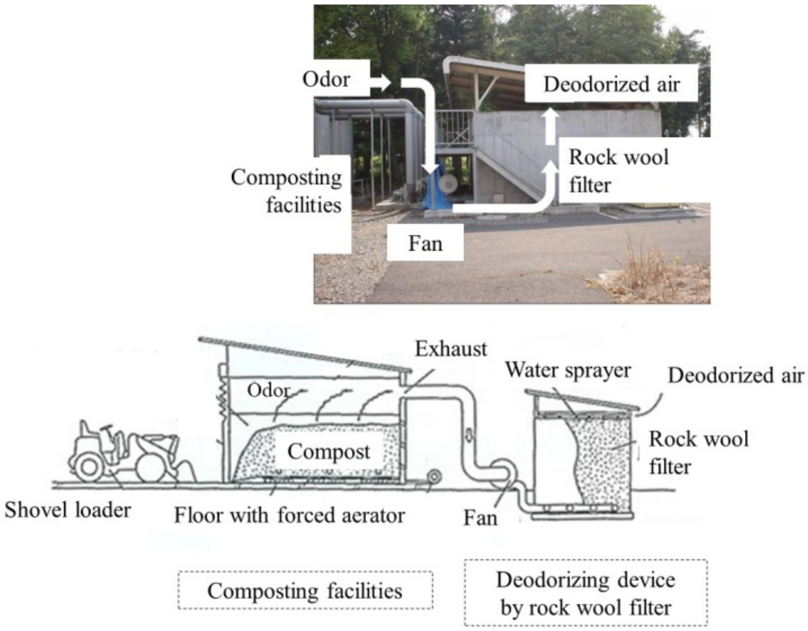

Fig. 20 Deodorizing device by rock wool filter adopted with exhaust form composting facilities.

BMP manuals [25, 26] describe five results of research and development as follows: (1) Odor removal with dust by use of oil emulsion. (2) Odor removal in exhaust from closed pig house by use of low-cost biofilter assembled with moist coconut husk and microorganisms. (3) Odor removal in exhaust from open-type pig house by shielding wall with spraying water. (4) Prediction and control of odor diffusion by computational fluid dynamics. (5) Evaluation of deodorizing effect of additives. Additionally, twelve case studies of BMP in livestock farms are presented in the manual [26].

7. Energy Production

Livestock waste contains 80% of organic matter on the dry basis. Biogas is produced from the organic matter by methane fermentation and is used as fuel having energy value 25.1 MJ (6,000 kcal)/m^3. More than one hundred facilities of methane fermenter are now in operation, mainly in Hokkaido, like EU. Among them, Yagi Bioecology Center [27] established in 1998 in Kyoto prefecture produces 2,000 m^3 of biogas from 56 m^3/day of the mixture of cattle, pig, and soybean-cake wastes (Fig. 21) a long time.

Fig. 21 Biogas production from livestock waste and food waste by methane fermentation.

Table 7 Power plants generated by the combustion of broiler litter in operation, Japan [28].

Power plant	Furnace	Power (kW)	Broiler litter combusted (t/year)	Start-up
Plant A	Fluidized bed	6,250	120,000	Nov. 2016
Plant B	Fluidized bed	1,950	42,000	May 2006
Plant C	Fluidized bed	3,000	75,000	May 2015
Plant D	Fluidized bed	1,500	100,000	Apr. 2002
Plant E	Fluidized bed	1,500	100,000	May 2012
Plant F	Stocker	11,350	132,000	May 2005
			Total 569,000	

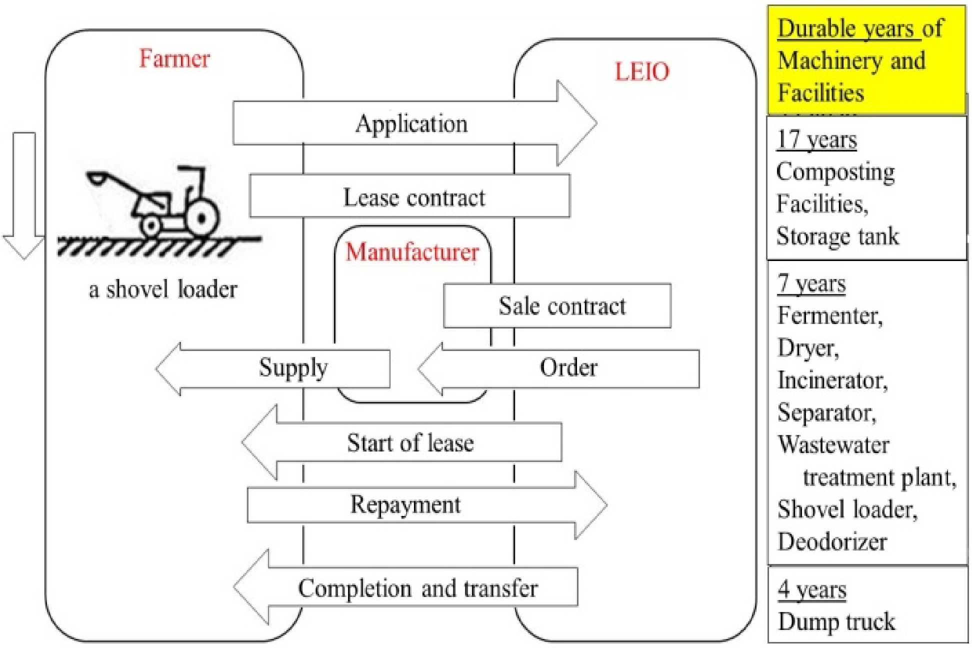

Fig. 22 LEIO lease system for machinery and facilities of livestock waste management.

The combustion of broiler litter in power plant generates electricity. Large power plants as shown in Table 7 burn 569,000 ton of broiler litter to generate electricity [28].

8. Financial Aid to Install Machinery and Facilities

Since 1976, the lease system for machinery and facilities of livestock waste management by LEIO (Livestock Industry's Environmental Improvement Organization) helps livestock farmers to get machinery and facilities by installment payments (Fig. 22).

At first, a livestock farmer applies to LEIO for the desired machinery or facilities. For example, the desired machinery is a shovel loader in Fig. 22. LEIO orders it from a manufacturer. LEIO pays the manufacturer in full and then the manufacturer directly supplies it to the farmer who can use it from that day. But the ownership of the shovel loader is with LEIO who leases it to the farmer.

The farmer repays to LEIO in annual installments of seven years that corresponds to its durable time as shown in Fig 22. For example, the durable time of the shovel loader is 7 years. Complete payment transfers the ownership of the shovel loader from LEIO to the farmer.

9. Conclusions

Solid matter of livestock wastes is converted into compost which could be widely distributed and recycled in cropland of agricultural farm. Liquid matter (wastewater or slurry) could be applied to cropland of livestock farms, but most of Japanese livestock farms do not have enough cropland to use liquid matter, except Hokkaido, northern area of Japan, like EU. Particularly pig farms have no area to spread wastewater. It should be purified to be discharged into public water bodies for environmental conservation. Financial aid to get machinery and facilities of livestock waste management is necessary for the farmers. Sustainable recycling of composting and environmentally friendly control wastewater and odors will be connected to the development of sustainable agriculture.

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