THE EFFECTS OF OPERATIONAL AND FINANCIAL FACTORS ON THE ECONOMICS OF BIOGAS PRODUCTION FROM DAIRY COW FECES AND WASTEWATER

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Summary

Biogas created from animal waste is a precious energy source. A practical and successful utilization of the biogas is not easy, because there lie some difficulties in biogas production and facilities investment. In this study, the requisites for a successful biogas utilization were discussed. The production results obtained in the previous operation of anaerobic digestion plant were used for the simulation. When the slurry heating was designed for constant biogas generation, depreciation costs of the facilities amounted 1,175,000 yen per year, and biogas productions at 24.5℃, 30.0℃ and 35.5℃ were 16.8m^3, 17.6m^3 and 25.1m^3, respectively. Removal ratios of organic matters were not so high. At 35.5℃, energy value of the biogas produced was estimated 125.5 Mcal per day, and the following heat loss(y Mcal/day) was brought about by the temperature difference (χ℃) between the digester and atmosphere;

$y = 0.769\chi - 5.375.$

The costs of biogas production per cow were assumed to decrease according to enlargement of feeding scale, especially on scales of more than 30 cows. On recent levels of costs and prices of energy in Japan, they were nearly equal to 2 to 3 fold of the price of municipal mixed gas when a anaerobic digester was compulsorily heated and kept at 30.0℃ or 35.5℃.

(**Key Words**: Biogas Utilization, Animal Feces, Animal Feeding)

Introduction

Biogas, which is created by the anaerobic digestion of animal feces and wastewater, is a valuable source of energy. The biogas utilizations in animal feeding have been often tried up to this time (Ross et al., 1989), but they were commonly passive trials in animal feeding of small scale and were often operated only in the tropical or subtropical zones. In the future, however, the biogas utilization in animal feeding can't be ignored, because an exhaustion of energy sources is being feared. Establishment of practical technique producing biogas from animal waste in the colder regions is also an important subject (Matsushige et al., 1990).

The biogas utilization in animal feedings of large scale will be affected by lots of requisites, such as climate (especially temperature), anaerobic digestion system and efficiency of biogas production, construction expenses of the digestion facilities, running cost including labor cost of management of the facilities, and so on. Commercial fuel prices are other important factors of biogas utilization. These factors vary according to individual circumstances of animal feeding, regions on the globe, or times of mankind living on the earth. Variations of these factors can be presumed among an extent given rise to in actuality.

Authors constructed and operated anaerobic digestion plant in the colder region of Japan using pressed-slurry of feces from cow feeding (Kobayashi et al., 1988). Techniques of managing the facilities in a desirable temperature condition and gas holding were also established (Kobayashi et al., 1988; Kobayashi, 1989). The operating results obtained are capable to be applied to presumption and discussion of a further biogas utilization in animal feedings.

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In this study, the requisites, which are required for a successful biogas production and utilization in cattle feeding of large scale, were discussed diverting the above results of anaerobic digestion and evaluating other factors mentioned.

Materials and Methods

Factors adopted as bases of evaluation and discussion

The requisites for a successful utilization of biogas depend on lots of factors concerning facilities construction and biogas generation, and on their interrelationship. The following factors were adopted as bases of evaluation and discussion for a successful utilization of biogas in animal feeding, and were put into the trial calculation; atmospheric temperature, feeding scale of animal (cow), administrating scale of the anaerobic digestion plant, construction expenses of the plant, running cost (including labor cost) of the plant, efficiency of biogas production in the plant, and the prices of commercial fuels.

Practical operation results of biogas production from animal waste

As the bases of efficiency of biogas production from animal waste and construction costs of anaerobic digestion plant, a practical operation results of biogas production in the anaerobic digestion plant from cow pressed-feces slurry in the Experiment Station, Tokyo University of Agriculture (NODAI) were applied.

Comparison of energy efficiency between direct *combustion of waste* and biogas utilization by anaerobic digestion

Comparison of energy efficiency between direct combustion of animal waste and biogas utilization by anaerobic digestion was tried, because in the tropic or subtropic zones animal feces loses its moisture by the natural sunshine and can be burned if it lies in small lumps. Urine and wastewater from animal feeding, however, are not likely to dry so fast as feces. But these are able to be used as fuel or manure especially in animal feedings of small scale.

Propositions for a successful biogas utilization

The following inequality formula was proposed as preliminary understanding of a successful biogas utilization from animal feeding;

$$(D.C. + L.C.)/T.E. \leqq F.P.$$

here D.C. means depreciation cost of the plant,
L.C. means labor cost and other running costs of the plant,
T.E. means total energy produced in the plant, and
F.P. means fuel price of a standard unit, especially that of petroleum and natural gas.

Results and Discussion

Operation results of input and output in the anaerobic digestion plant in the Experimental Station, NODAI

The system flow of pressed-feces slurry digestion plant in Nasu Experimental Station, NODAI, is showed in figure 1, and the construction expenses demanded for the facilities are showed in table 1. The plant worked for administration of feces and urine/slurry from feeding 60 cows. In the administration, only the pressed slurry was offered for the digestion, and the pressed dregs

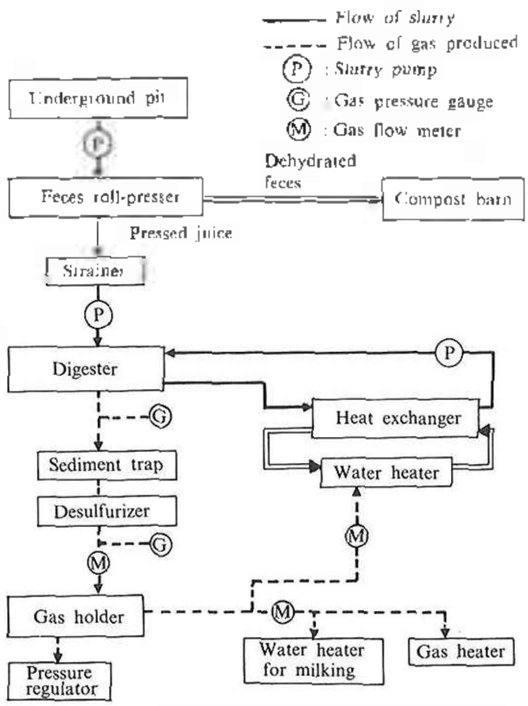

Figure 1. System flow of the anaerobic digestion plant of pressed-feces slurry in Nasu Experimental Station*, Tokyo University of Agriculture.

* Closed at present.

TABLE 1. CONSTRUCTION EXPENSES DEMANDED FOR THE ANAEROBIC DIGESTION FACILITIES IN NASU EXPERIMENTAL STATION, NODAI

Installation	Supply price (yen)	Life available (year)	Depreciation (yen)
Feces roll-presser	2,000,000	5.0	400,000
Anaerobic digester	5,200,000	20.0	260,000
Biogas holder	2,800,000	10.0	280,000
Slurry pump for input & circulation*	600,000	10.0	60,000
Vessel for desulfurization & sedimentation	450,000	10.0	45,000
Heat exchanger	900,000	10.0	90,000
Methane boiler	200,000	5.0	40,000
Slurry pump for drawing up	1,500,000	5.0	300,000
Basement	1,800,000	30.0	60,000
Total (Dispensable)	11,050,000	–	1,045,000
Total (Slurry heating)	12,150,000	–	1,175,000
Total (Satisfactory & slurry heating)	15,450,000	–	1,535,000

* Relevant connection pipes are included.

were fermented for direct scattering in the field. A daily flow of the effluent from the plant was 1,550 *l* in average. Solids ratio of the pressed dregs was calculated 23.0% in average in several measurements. A temporary investment to the plant amounted to 12,150,000 yen (circa US$ 93,500) when the satisfactory units were summed up. An annual depreciation amounted 1,175,000 yen (circa US$ 9,000) in the same case.

The reduction of organic matters and the relevant indices of pressed-feces slurry by the anaerobic digestion are showed in table 2. The removal ratios of organic matters were not so high.

The biogas production in the plant is showed in table 3. Through the period of one year, 6,700m^3 biogas was produced from 2,835kg T-SS, which corresponded to 33,500 Mcal energy (energy value of the biogas was calculated from the methane content of it, that is 5.00 Mcal/m^3 CH_4).

During the operation of the plant, the digestion temperature was varied in the range of 24.0-37.0℃, and so the effect of the digestion temperature on the biogas production was analyzed. The result is showed in table 4. Higher temperature was more effective for higher biogas generation. At lower temperatures, heat loss from

TABLE 2. REDUCTION OF ORGANIC MATTERS AND RELEVANT INDICES OF PRESSED-FECES SLURRY BY THE ANAEROBIC DIGESTION*

Indices	pH	T-S mg/l	T-SS mg/l	V-SS mg/l	BOD mg/l	COD mg/l	T-N mg/l
Feces slurry	7.0	73,000	47,000	34,000	49,000	80,500	2,980
Effluent**	7.7	56,000	43,000	29,000	32,000	53,600	2,140
Removal percent (%)	–	23.3	8.5	14.7	34.7	33.4	28.2

* Figures show the averages of sample picked up 18 times during 12 months. The digester was held at 24.0-37.0°C (30.0°C in average) throughout the period.

** A daily flow of the effluent was 1,550 *l* in average.

TABLE 3. BIOGAS PRODUCTION* IN THE ANAEROBIC DIGESTION FACILITIES IN NASU EXPERIMENTAL STATION, NODAI

Management indices	Pressed-feces slurry (m^3)	Biogas produced (m^3)	Biogas used for digester (m^3)	Biogas available (m^3)
Average per day	1.55	18.31	–	–
Total in a year	567	6,700	2,542	4,158

* Average methane concentration was 61.6%.

TABLE 4. EFFECTS OF FERMENTATION TEMPERATURE ON BIOGAS GENERATION IN THE ANAEROBIC DIGESTION OF ANIMAL WASTE*

Fermentation temp.** (℃)	Biogas generation in initial 24 hr (m^3)	Biogas generation in perfect digestion (m^3)
24.5	5.73	16.83
30.0	6.01	17.61
35.5	9.30	25.10

* 1,550 l of pressed-feces slurry per day was submitted to the digestion.
** Ten days, when the digester temperature were adjusted to fixed temperatures, were selected from the fermentation record in each case during the period.

the digester and that for heating fresh slurry will be smaller. Therefore the relation between digestion temperature and heat loss was analyzed, and the following formula was obtained (Kobayashi et al., 1989);

$$Y = 0.769X - 5.375$$

here Y means heat loss (Mcal) per day and X means temperature difference between the digester and atmosphere.

Even if the heat loss was less at the lower temperature, the energy of biogas generated could compensate it. That proved a profitability of digestion in the higher temperatures.

In out practical operation, the digester slurry was usually held at 30.0℃ and near temperatures because of a expectation of relatively higher biogas generation.

The relation between ambient temperature and biogas utilization in the anaerobic digestion plant

The biogas generation in the anaerobic digestion is greatly influenced by the ambient temperature. When the ambient temperature is lower, not only the biogas generation is lower, but a heat loss during the digestion is more increased. The heat loss comes from necessity of heating fresh slurry and heat radiation from the digester surface. In these cases, the utilizable biogas will decrease because a part of the biogas produced is consumed for the slurry heating in usual cases.

The relation between ambient temperature and biogas production/heat loss is showed in figure 2 based on our previous study (Kobayashi et al., 1991). The temperature at 9 o'clock in the morning was applied to the daily average The heavy lines show "utilizable energy" when the

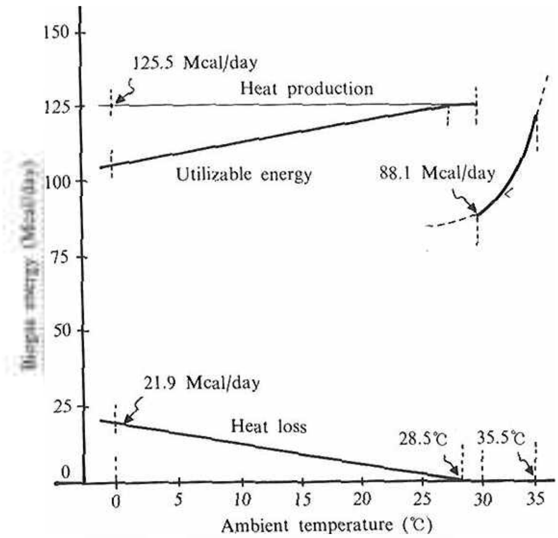

Figure 2. The relation between ambient temperature and biogas production / heat loss in the anaerobic digestion plant*

* The digester slurry is compulsorily heated and held at 35.5 ± 0.5℃ at the ambient temperature less than 30.0℃. At the ambient temperature more than 28.5℃. The heat loss is neglected.

digester slurry was compulsorily heated and held at 35.5 ± 0.5℃ under the condition of ambient temperature less than 30.0℃. In this case, the heat loss is neglected if the ambient temperature is more than 28.5℃. The phenomenum will have been derived from the great "specific heat" of slurry. The compulsory heating is more desirable under the condition of ambient temperature less than 35.5℃, because the efficiency of biogas generation is much lower at 30.0℃ than at 35.5℃. Even though the additive investment is necessary for the compulsory heating, the equipment for heating is practical.

The relation between herd size and plant expenses

In figure 3, the depreciation costs of the facilities of the anaerobic digestion and the labor costs including other running expenses in a year are showed accompanied with the herd size of cow. At drawing the figure, the followings were presumed; every cost will vary step by step according to every 10 cows, the depreciation cost at the herd size of 10 is 34% of that at the herd size of 60, and the labor cost including other running costs is equal at all the herd size (because the labor efficiency will be lower at the smaller herd size). Both costs at the herd size of 60 already mentioned in the previous section were applied. Adding these values the total costs were calculated.

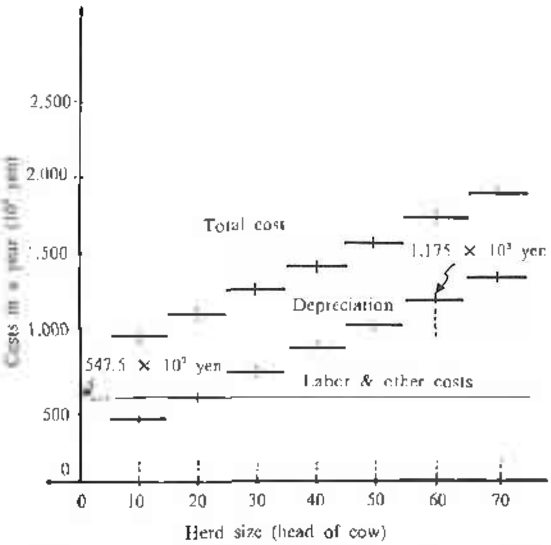

Figure 3. The relation between herd size of cow and costs for biogas production

Although the costs calculated are the instances in Japan and they are in markedly high level, the prices of energy, which is imported and consumed in Japan, are also in high level. If the energy value of biogas is estimated on the same base with the petroleum sources, the comparison will be reasonable.

Comparison of the costs for biogas production with the energy value generated

In figure 4, the total costs per cow for the biogas production are showed in each variation of 10 cows. They became rapidly higher at lower herd size. The energy value of biogas produced is showed as a dotted line. It was calculated as follows, and in this case the anaerobic digestion at 35.5℃ (compulsory heating of slurry) was assumed;

25.10 m^3/day × 365 day × (5.00×10^3) kcal/m^3 × (1.40×10^{-2}) yen/kcal × 1 head/60 head = 1.07×10^4 yen

here 5.00×10^3 kcal/m^3 is energy value of biogas, 62% of which is methane, 1.40×10^{-2} yen/kcal is price of municipal mixed gas. After all the energy value of biogas produced is equal to 1.07×10^4 yen per cow, year.

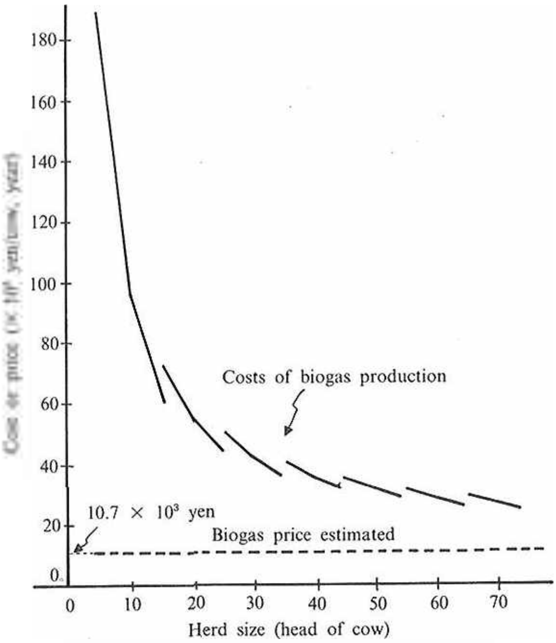

Figure 4. Comparison of the costs for biogas production with the price of municipal mixed gas*

* The price at consumers was estimated 1.40×10^{-2} yen/kcal.

In this comparison, the heat loss caused by the temperature difference between atmosphere and digester/fresh slurry is not considered. When the ambient temperatures are less than 28.5℃, the utilizable biogas will more decrease and the energy value of it will become lower. But the heat losses will be not so high, e.g. when the ambient temperature (daily everage) is 12.0℃, the heat loss will become 12.7 Mcal per 60 cows, day, which corresponds to only 10.1% of the total produced, as shown in figure 2.

The calculation here contains lots of ideal simulations. In the practical operations there will happen various troubles, and so the efficiency of biogas production and utilization will go down than the result shown in figure 4.

We can easily presume that the energy price from petroleum, atomic power and other origins will arise. At the same time, techniques of biogas production from animal waste will be developed by using various bioreactors, in which the systems of keeping methanogenic bacteria in digester (Daigger et al., 1990; Grontenhuis et al., 1991; Jeweld et al., 1981; Lewandowski et al., 1990) or of breeding methanogenic bacteria being active at lower temperatures (Matsunaga et al., 1991; Sanz et al., 1990) were recently investigated.

Comparison of biogas energy with combustion *energy of the feces-pressed slurry*

In figure 5 the schema of energy generation in combustion of feces-pressed slurry from feeding 60 cows is showed. On the simulation, the following values were estimated from the previous measurement (unpublished); 40 kg daily excreta/cow, 15.0% solids content of it, 54.2% pressed dregs and 45.8% pressed slurry from fresh excreta, 5.5% solids content and 4.6% organic matter of the pressed slurry, 450 *l* water addition to it before digestion, and 5,130 kcal/kg combustion energy of slurry solids (Palz et al., 1983). As the result, the energy content of the daily slurry digested was estimated 260 Mcal. It is nearly equal to 2.1 fold of biogas energy generated by the anaerobic digestion at 35.5℃.

At the direct combustion, in fact, a dehydration procedure or a much evaporation heat is demanded. Therefore the above apparent combustion energy will be reduced. Also at the biogas production, some energy for slurry heating and electric power are demanded. But it was confirmed that the biogas production can bear comparison with the direct combustion of slurry.

In animal feedings of large scale, certain amounts of expenses are demanded for administration and utilization of animal waste. If we have an idea that the expenses for the anaerobic digestion are needed additionally to usual administrations, the burden of investment and labor for the anaerobic digestion will be reduced.

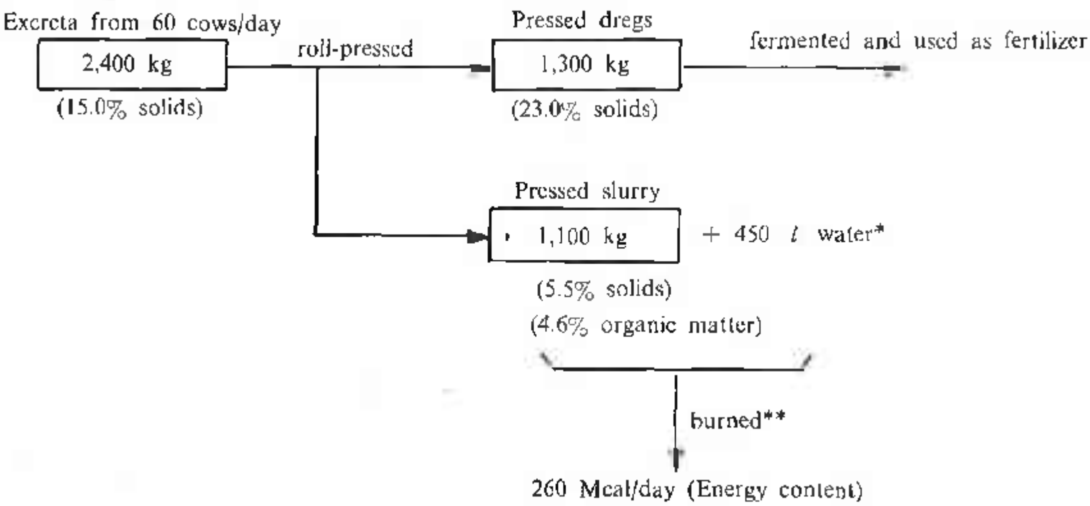

Figure 5. Schema of energy generation in combustion of the feces-pressed slurry from cow feeding

* Drainage water used for cleaning milkers, etc.

** One kg of slurry solids was converted 5,130 kcal.

As requisites of a successful utilization of biogas from feces and wastewater of animal feeding, the followings will be indicated;

1) reduction of construction costs of the plant,
2) ascent of energy price caused by exhaustion of energy sources,
3) animal feeding of a large scale (e.g. more than 30 cows),
4) compulsory heating of slurry in digester (35~40℃),
5) maintaining good biogas generation without troubles in operation, and
6) capability of treating the effluent (usually returning back to the field).

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