〈ノート〉

Study towards 50% Energy-Saving in Wastewater Treatment Plants

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Abstract

The Ministry of Land, Infrastructure, Transport and Tourism（MLIT）has set energy-saving in wastewater treatment plants（WWTPs）by 50% as a target to be reached by 2040. The Japan Institute of Wastewater Engineering and Technology（JIWET）has performed a joint research with manufacturers and local public organizations to save energy consumption in WWTPs.

As a result of the research, introducing newly developed equipment such as membrane type air diffusers and energy saving type mixers for reactors can reduce energy consumption significantly in wastewater treatment process. Air flow control system using ammonia sensors is effective to save energy. In sludge treatment process, newly developed equipment such as energy-saving sludge thickeners and energy-saving sludge dewatering machines can significantly reduce energy consumption.

The case study showed that 32% energy reduction of a WWTP by combination of these newly developed energy-saving type facilities was achieved.

Keyword : wastewater treatment, energy-saving, membrane type air diffuser, energy-saving sludge thickener

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1. Introduction

Wastewater Treatment Plants（WWTPs）in Japan consume much energy which was 0.7%（7.2 billion kWh）of Japan's total energy consumption in fiscal year 2010.

This paper reports the evaluation of the reduction of energy consumption and reduction of greenhouse gas（GHG）emission due to the introduction of newly developed energy-saving type equipment in WWTPs in Japan. Also, this paper introduces the energy-saving effect on a WWTP by combination of these equipment.

2. Energy-saving equipment in wastewater treatment process

2. 1 Membrane type air diffusers

Membrane type air diffusers（**Fig. 1**）are able to reduce energy consumption due to high oxygen transfer efficiency. Membrane type air diffusers generate smaller diameter of air bubbles than those generated by conventional air diffusers. Then, smaller the air bubbles, higher the oxygen transfer efficiency and smaller the air flow to reactors. Small air flow leads to small energy consumption. Thus, membrane type air diffusers can reduce energy consumption. Moreover, even during a low air flow rate, the air pressure inside the air diffuser is higher than the water pressure, which prevents intrusion of wastewater, and therefore, as compared to the conventional air diffusers, the air flow rate can be adjusted in a wide range.

Fig. 1 Example of membrane type air diffusers

To verify energy-saving effect, power consumption per unit oxygen supply by conventional air diffuser and by membrane-type air diffuser was calculated. Results are shown in **Fig. 2**. While power consumption of conventional diffuser was 0.39 kWh/kgO_2, that of the membrane-type diffuser was reduced to 0.21 kWh/kgO_2.

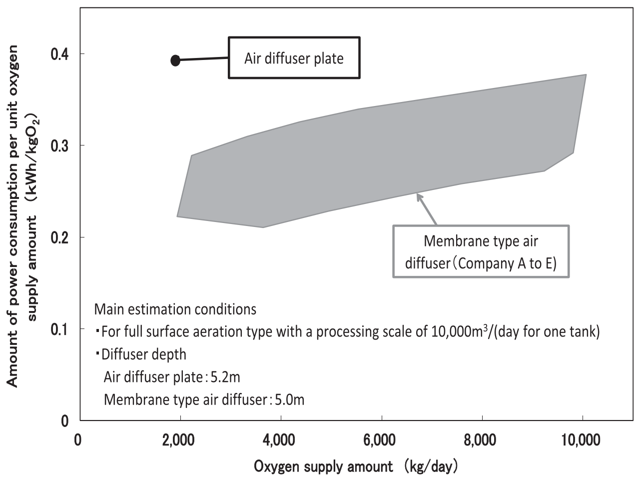

Fig. 2 Relationship between the oxygen supply amount by membrane type air diffuser and power consumption per unit oxygen supply amount

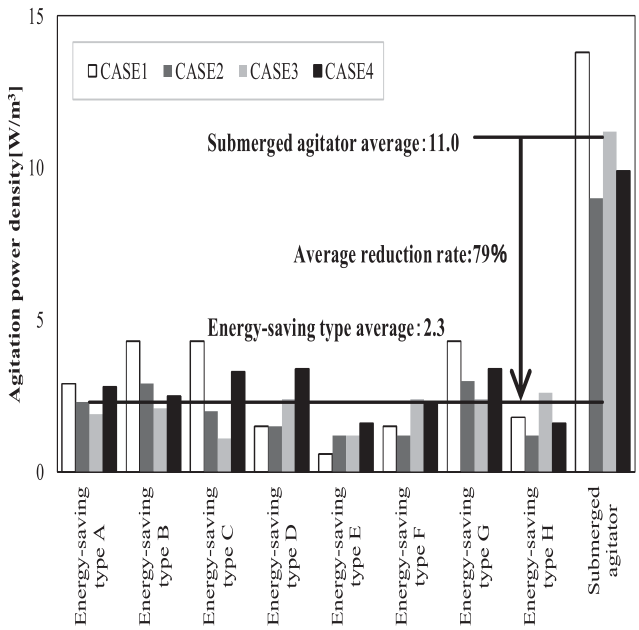

Fig. 4 Effect of energy-saving mixers according to case study

2. 2 Energy-saving type mixers for reactors

In order to realize the energy-saving effect in a wastewater treatment process that accounts for approximately a half of energy consumption of WWTPs, it is effective to replace submerged mixers having a high mixing power density to energy-saving type mixers. Several types of energy-saving type mixers have been developed as shown in **Fig. 3**. The effect of introduction of energy-saving type mixers is shown in **Fig. 4**. As a result of the case study performed for four cases in which a standard depth tank and a deep tank were used for the conventional activated sludge process and the A_2O process, the rate of reduction in mixing power density as compared to that of submerged mixer before installation of the energy-saving agitator was estimated to be 66 to 96% (79% as average).

Also, as a result of investigation of the installation case examples for seven sewage treatment plants in which an energy-saving mixers were actually installed, the reduction in mixing power density was 49 to 84% (71% as average) as shown in **Table 1**.

Table 1 Results of installation of energy-saving mixers in WWTPs

	After installation of energy saving type	Before installation of energy saving type (Submerged mixer)
WWTP A	2.8 W/m^3 (▲ 71 %)	9.6 W/m^3
WWTP B	2.1 W/m^3 (▲ 75 %)	8.3 W/m^3
WWTP C	4.7 W/m^3 (▲ 49 %)	9.2 W/m^3
WWTP D	3.2 W/m^3 (▲ 66 %)	9.5 W/m^3
WWTP E	3.0 W/m^3 (▲ 83 %)	17.7 W/m^3
WWTP F	1.4 W/m^3 (▲ 84 %)	8.9 W/m^3
WWTP G	3.2 W/m^3 (▲ 72 %)	13.4 W/m^3

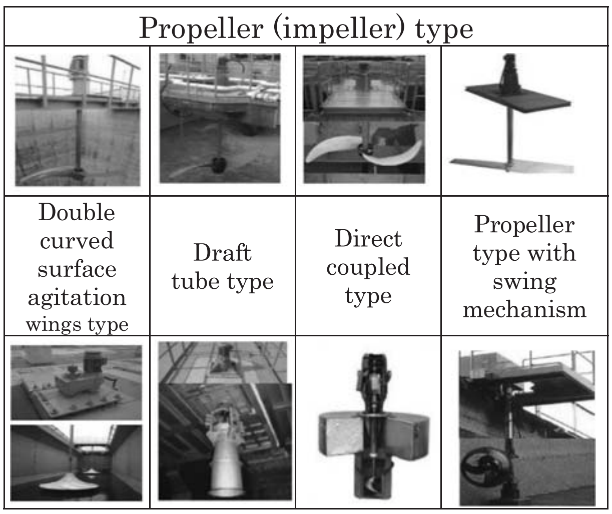

Fig. 3 Energy-saving type mixers

2. 3 Air flow control system using ammonia sensor

DO control is usually exercised to control air flow to reactors in Japan. DO is measured near outlet of reactors and is not reflected inflow BOD and ammonia loading correctly. Usually, excessive air flow is supplied to reactors to keep DO at designated concentration.

Ammonia sensors are installed at inlet and outlet of reactors to measure ammonia concentration at both locations in this system. Measuring ammonia concentrations at two locations continuously, this system enables to supply necessary air flow ; thus, this system enables to energy saving by reducing excess air flow.

Case study showed that 22% and 16% energy reduction could be achieved depending on the adopted control method.

3. Energy-saving methods for sludge treatment process

3. 1　Energy-saving sludge thickeners

Several types of energy-saving sludge thickeners have been developed such as differential rotary screw thickener, belt type filtering thickener (stainless belt), and belt type thickener (plastic belt). The mechanism of differential rotary screw thickener is as follows (**Fig. 5**).

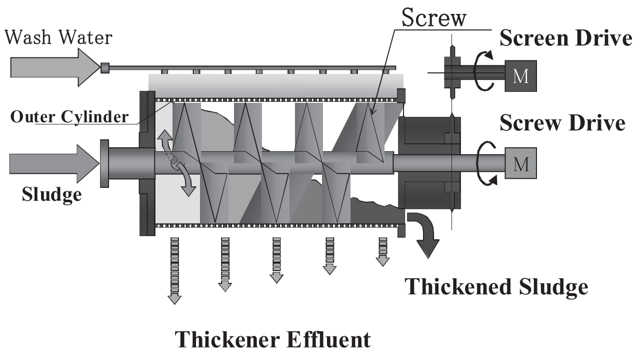

Fig. 5　differential rotary screw thickener

After mixed with coagulant, sludge is transferred into thicker. Sludge is thickened on outer screen which rotates to clean up with wash water. Screw rotates opposite direction of outer screen and conveys sludge toward outlet. Through this process, sludge is thickened and excess water is removed as thicker effluent. Power output is 0.6–7.4 kW which depends on outer screen diameter. Screw rotates slowly (3–20/min) and screen also rotates slowly (10–20/min). Solid contents of thickened sludge is around 4 %. Effect of reduction in the amount of energy consumption and greenhouse gas (GHG) emission by differential rotary screw thickener were estimated and compared with those by conventional sludge thickener (centrifugal thickener) is shown in **Fig. 6** and **Fig. 7**.

Condition and range of estimation of energy consumption and GHG emission of the thickening facility are shown in **Table 2** and **Fig. 8**, respectively. Since the required auxiliary equipment differs depending on the type of the energy-saving sludge

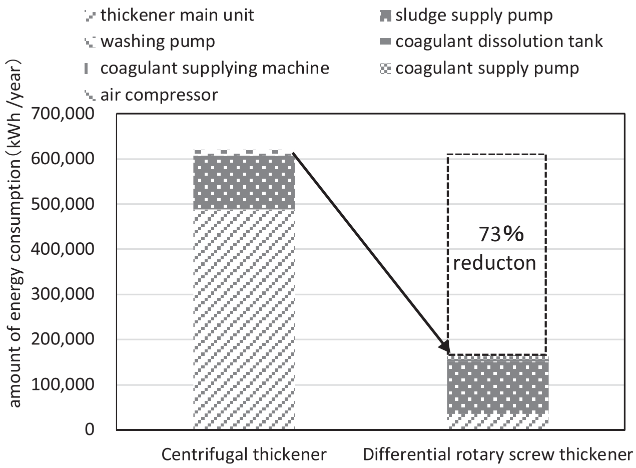

Fig. 6　Reduction of energy consumption

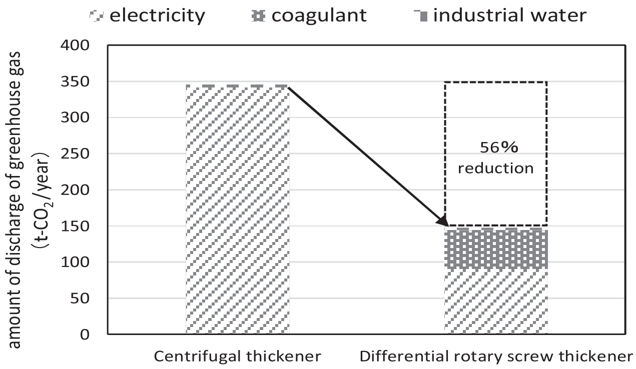

Fig. 7　Reduction of GHG emission

Table 2　Condition of estimation

Item	Terms and conditions
Max. daily planned wastewater flow	70,000 m^3/day
Planned inflow SS concentration	200 mg/l
Planned discharge SS concentration	10 mg/l
Wastewater treatment process	Conventional activated sludge process
Target sludge	Excess sludge
Sludge concentration	0.6 %
Thickener operation time	24 hours/day, 7 days/week

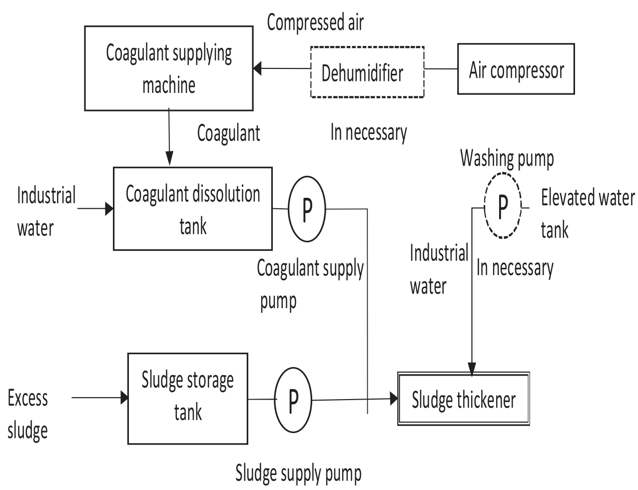

Fig. 8　Range of estimation on sludge thickening facility

thickener, the amount of energy consumption included auxiliary equipment.

Concerning energy-saving thickening facility, 73% reduction of energy consumption, 56% reduction of the GHG emission were estimated.

Breakdown of energy consumption of the sludge thickening facility is shown in **Fig. 9** and **Fig. 10**. Since energy consumption by main equipment (thickener) decreases significantly, proportion of energy consumption of auxiliary equipment such as excess sludge supply pumps increases. To achieve the target of 50% reduction of 50% of energy consumption of WWTPs, energy consumption by auxiliary equipment also needs to be reduced in the future.

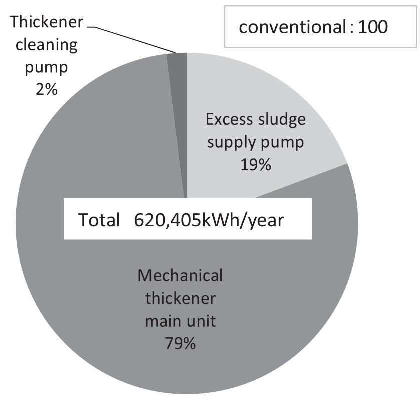

Fig. 9 Energy consumption of centrifugal thickening facility

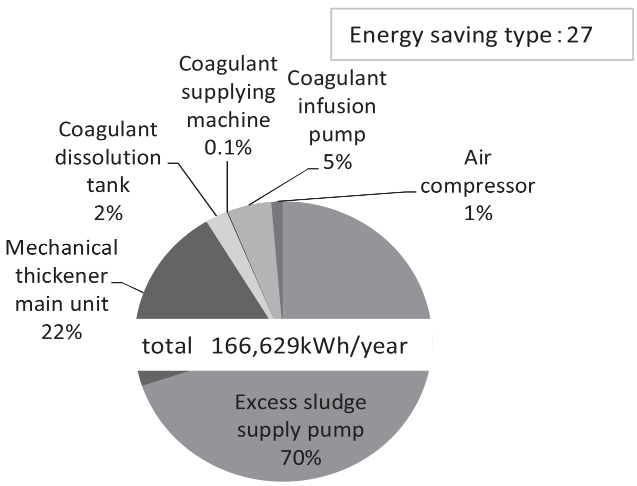

Fig. 10 Energy consumption of differential rotary screw thickener

3. 2 Energy-saving sludge dewatering facility

Several types of energy-saving sludge dewatering machines have been developed such as hybrid-type screw press dewatering machine, high-efficiency two-axis screw-press dewatering machine and energy-saving centrifugal dewatering machine. The mechanism of high-efficiency two-axis screw-press dewatering machine is as follows (**Fig. 11**).

Thickened sludge with coagulant is pumped to

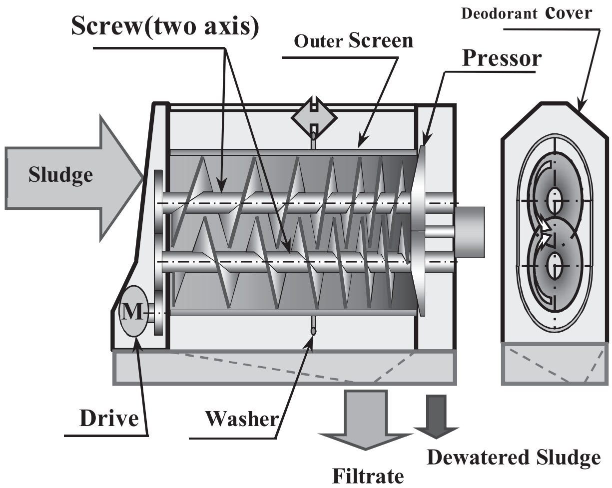

Fig. 11 high-efficiency two-axis screw-press dewatering machine

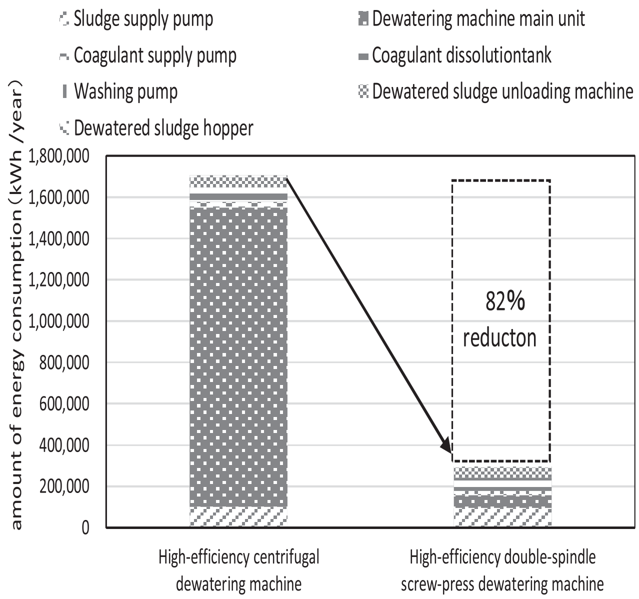

Fig. 12 Reduction of energy consumption

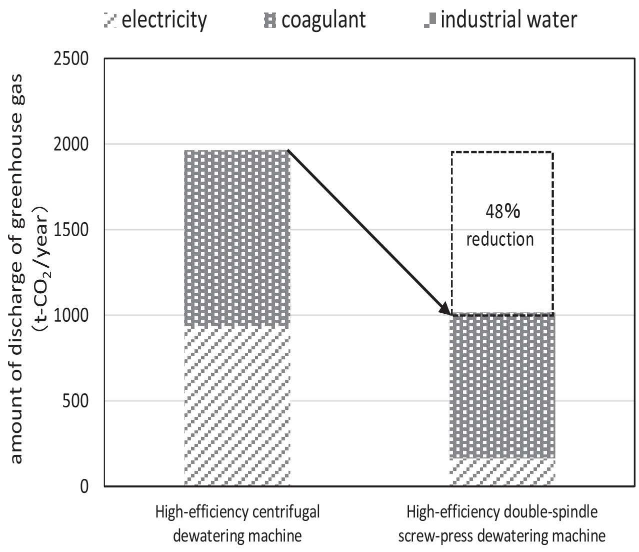

Fig. 13 Reduction of GHG emission

Table 3　Condition of estimation

Item	*Design value*
Max. daily planned wastewater flow	*200,000 m^3/day*
Planned inflow SS concentration	*200 mg/l*
Planned discharge SS concentration	*20 mg/l*
Discharge system	*Separate sewer system*
Wastewater treatment process	*Conventional activated sludge process*
Thickening process	*Gravity thickening＋mechanical thickening (separation and thickening)*
Sludge to be dewatered	*Mixed raw sludge*
Loss on ignition (VS)	*80 to 83 %*
Solids concentration (TS)	*3.4 %*
Fibrous object (100 mesh)	*20 %*
Dewatering machine operation time	*24 hours/day, 7 days/week*
Type and quantity of dewatering machines	*Screw diameter φ800×4 units (Of which one unit is spare)*

dewatering machine

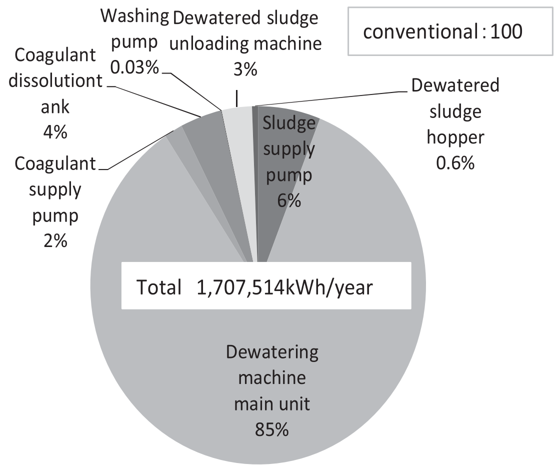

Fig. 14　Breakdown on energy consumption by centrifugal dewatering machine

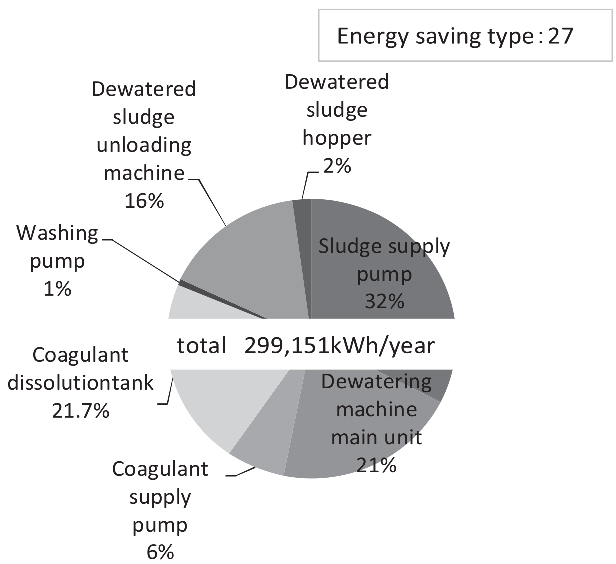

Fig. 15　Breakdown on energy consumption by high-efficiency two-axis screw-press dewatering machine

dewatering machine. Slowly rotating two axis enhance shear force and pressure to dewater. Also, presser keeps high pressure. These mechanism enables effective dewatering. Power output is 1.25-11.3 kW which depends on diameter of outer screen.

Estimated results of energy consumption and GHG emission for the high-efficiency two-axis screw-press dewatering machine are shown in **Fig. 12** and **Fig. 13**, and condition of estimation is shown in **Table 3**.

Concerning energy-saving dewatering facility, 82% reduction of energy consumption, 48% reduction of GHG emission were estimated.

Breakdown of energy consumption of the sludge dewatering facility is shown in **Fig. 14** and **Fig. 15**. Since energy consumption by main equipment (dewatering machine) decreases significantly, proportion of energy consumption of auxiliary equipment such as sludge supply pumps increases.

4. Study on the effect of energy-saving technology on WWTP

4. 1　Current status of *A* WWTP

We conducted a case study to introduce newly developed technologies. The purpose of the case study is to examine the energy saving effect on a WWTP and to extract issues to achieve the goal of 50% energy reduction. The WWTP targeted for the case study was selected from medium-sized WWTPs with an average daily flow of around 100,000 m^3/day. The reason is that the energy consumption of WWTPs with an average daily water volume of about 50,000 m^3/day to 150,000 m^3/day accounts for 30% of the energy consumption of WWTPs throughout Japan, according to a study conducted by MLIT. In addition, we selected a WWTP that did not have an incinerator. The reason is that the sewerage law was revised and MLIT is promoting the use of sewage sludge as fuel such as the digestion gas power generation in place to incinerators. *A* WWTP was selected to conduct the case study. Overview of *A* WWTP is shown in **Table 4**. Breakdown of energy consumption in *A* WWTP is

Table 4　Overview of *A* WWTP (2015)

Item	Terms
Average daily flow	127,169 m^3/day
Waste water treatment process	Conventional activated sludge process
Sludge treatment process	Thickening → Digestion → Dewatering

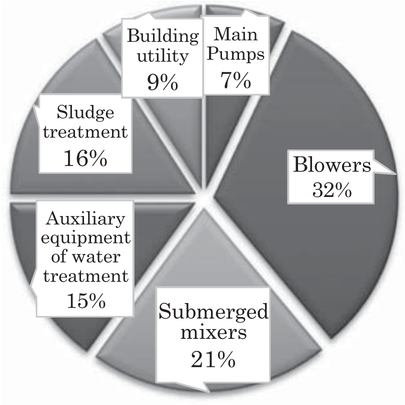

Fig. 16 Breakdown on current energy consumption (Total 4,820,000 kwh/year)

shown in **Fig. 16**. In addition, the digestion gas generate 1,390,928 kwh/year of power.

The wastewater treatment process accounts for around 70%. In particular, blowers and submerged mixers together exceed 50%. The sludge treatment process accounts for 16%

4. 2 Energy saving in wastewater treatment process

(1) Energy saving by reducing air flow

We estimated energy consumption when all existing submerged mixers (oxygen transfer efficiency was 25 %) would be replaced to membrane-type diffusers (average oxygen transfer efficiency was 33%).

Energy reduction=

1,555,952 kWh/y(current energy consumption) ×(1−25/33)=377,685 kwh/y

(2) Energy Saving of mixing power

By adopting the membrane-type diffusers which had also mixing function, energy for mixing in the aerobic by submerged mixes tank would not be necessary. In addition, we estimated energy consumption when updating all existing submerged mixers in anoxic tanks (power : 3.7 kW or 5.5 kW) to energy-saving mixers (power 0.75 kW) without changing the mixing capacity and operating time of each mixer.

Energy reduction=

1, 015, 668 kWh/y (current energy consumption) −0. 75 kW×0. 9 (load factor) ×77, 249 h (Actual annual operating time)=963,524 kWh/y

4. 3 Energy saving in sludge treatment process

(1) Energy Saving of sludge dewatering

We estimated energy consumption when existing high-efficiency centrifugal dewatering machines would be replaced to high-efficiency two-axis screw press dewatering machines.

Energy reduction=

121,429 kwh/y(Current energy consumption) ×0.82(Reduction Rate)=99,572 kwh/y

(2) Energy saving of sludge thickening

A WWTP had adopted energy saving type thickeners already. So, we did not expect energy reduction.

(3) Energy saving of mixers in digestion tank

We estimated energy consumption when existing high-speed mixers (11 kw) would be replaced to low-speed impeller type mixers (2.2 kw).

Energy reduction=

115,751 kWh/y(current energy consumption) ×(1−2.2/11)=92,600 kWh/y

(4) Total energy reduction of *A* WWTP

Energy reduction in *A* WWTP is summarized in **Table 5**. The rate of reduction was 32%.

Table 5 Summary of energy reduction in *A* WWTP

Facility	Reduction
Blowers	377,685 kWh/year
Submerged mixers	963,524 kWh/year
Sludge Dewatering	99,572 kWh/year
Sludge Thickeners	0
Mixers in digestion tank	92,600 kWh/year
Total energy reduction	1,533,381 kWh/year
Current energy consumption of *A* WWTP	4,820,000 kWh/year
Rate of Reduction	32 %

As mentioned above, the amount of electricity generated by the digestion gas at *A* WWTP is currently 1,390,928 (kwh/year), corresponding to about 30% of the energy consumption. Therefore, while continuing efforts to save energy, it is effective to reduce the energy consumption by fossil fuels by increasing the digestion gas power generation facilities.

5. Conclusion

(1) There are newly energy-saving equipment which can reduce energy consumption more than 50% than conventional equipment

(2) To reduce energy consumption, it is also important to save energy consumption of auxiliary equipment such as sludge supply pumps.

(3) Replacing submerged mixer to membrane-type

diffusers is effective for energy saving.

(4) The case study showed that 32% energy reduction of a WWTP by combination of newly developed energy-saving type facilities was achieved.

(5) It can be presumed that increasing the digestion gas power generation facilities is effective to reduce the energy consumption by fossil fuels.

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下水処理場における50%の省エネルギーについて

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概　　要

国土交通省は，下水処理場のエネルギー使用量を今後20年で50%削減する目標立てた。日本下水道新技術機構では，この目標達成のために，水処理においては微細気泡を発生させるメンブレン式の散気装置を導入し反応タンク撹拌機も省エネ型にすること，また，省エネ型の汚泥濃縮機及び汚泥脱水機を導入した場合のケーススタディ等を行った。その結果，改築時に既存システムを前述の省エネ機器等に変更していけば50%の省エネは実現可能性があることが示された。

キーワード：下水処理，省エネ機器，メンブレン式散気装置，省エネ型濃縮機，省エネ型脱水機