Energy Management in Sewage Treatment Facilities

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Dr. Hee-Jun Kim

R&D Center, Chief/Director

JIU Corporation

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I Background

Current Status

❖ Energy Consumption in Sewage Treatment Facilities

- Annual energy consumption in sewage treatment facilities : 395,121 TOE (in 2007)
- Among them, electric use occupies 98.6%
- Electric use per flow : 0.29 kWh/m^3
- Electric use per BOD removal : 2.353 kWh/kg BOD c.f) US, EU : 1.5 kWh/kg BOD
- Faction of electricity used in sewage treatment facilities reaches 0.5% of national electricity usage.
- Energy self-sufficiency of sewage treatment facilities is only 0.8%

Note) TOE : Tonnage of Oil Equivalent, the amount of energy released by burning one tonne of crude oil ≈ approximately 42 GJ (10^7 Kcal)

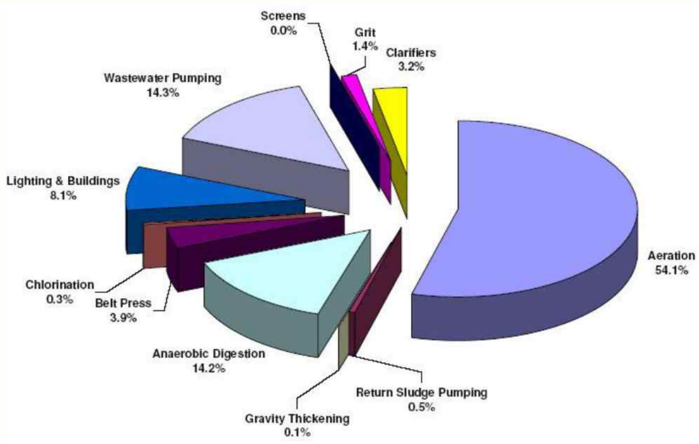
Note) Energy self-sufficiency : (Renewable Energy production + Energy saving)/Annual electric use

❖ Energy Consumption in sewage treatment operations (2008)

Energy related operation	Aeration	Sewage pumping	Dewatering	Sludge pumping	Discharge pumping	Anaerobic Digestion (mixing)	Thickening, screen, etc.
Fraction (%)	40.1	21.3	6.4	3.6	2.3	1.4	23.9

Energy Used in Wastewater Treatment (US)

- Energy Consumption in sewage treatment with AS Process



Electricity Requirements for Activated Sludge Wastewater

Derived from data from the Water Environment Energy Conservation Task Force *Energy Conservation in Wastewater Treatment*

Electricity Used in WWTF

- Annual Electric Use in Sewage Treatment Facilities

Year	2002	2003	2004	2005	2006	2007	2008	2009
Annual Expenses (million USD)	331.9	385.8	426.1	464.6	531.5	590.5	633.6	711.1
Annual Electricity Cost (million USD)	70.3	78.1	86.7	93.0	102.5	113.7	125.1	141.9
Electricity/Total (%)	21.2	20.2	20.4	20.0	19.3	19.3	19.7	20.0
Electricity Cost Growth (%)	-	11.1	11.0	7.2	10.3	10.9	10.0	13.5

- Electric Use in Sewage Treatment Facility with Different Capacity

Capacity (m^3/d)	Number of Facilities	Total Electric Cost (thousand USD /year)	Average Electric Cost (thousand USD /year)	Electricity Cost per Sewage Flow (cent/m^3)	Electricity Consumption (kwh)	Electric Use per Flow (kwh/m^3)
500 ~ 1,000	53	877.8	16.6	10.4	10,683,210	1.26
1,000 ~ 5,000	102	3,991.9	40.3	6.6	71,014,710	1.18
5,000 ~ 10,000	47	4,254.5	90.5	5.1	59,632,253	0.72
10,000 ~ 50,000	87	18,483.0	217.4	3.4	331,990,571	0.62
50,000 ~ 100,000	23	9,131.3	397.0	2.3	325,614,887	0.83
100,000 ~ 500,000	33	39,736.8	1,204.1	2.1	863,180,857	0.46
500,000 ~	14	52,591.3	3,756.5	1.6	847,361,345	0.26

Note) Average annual electric consumption of 1 household(4 persons) in Seoul city is about 4,800 kwh.

Basic Plan for Energy Self-Sufficiency

❖ Basic Plan for Energy Self-Sufficiency in Sewage Treatment Facilities

Main Goal

Energy Self-Sufficiency in Sewage Treatment Facilities in year 2030

: 50% in 343 facilities

Phase 1 ('10 ~ '15)
- Energy self-sufficiency 18%
- Completion of biogas (16.4%) and small hydro power (0.6%) introduction
- Energy saving, solar power and wind power introduction (1%)

Phase 2 ('16 ~ '20)
- Energy self-sufficiency 30%
- Expansion of energy saving (2%) and solar power production (4.6%)
- Completion of wind power introduction (5.4%)

Phase 3 ('21 ~ '30)
- Energy self-sufficiency 50%
- Completion of energy saving (2%) and solar power production project (18%)

(Ministry of Environment, 2010)

Basic Plan for Energy Self-Sufficiency

❖ Some Strategies for Upgrade Energy Self-Sufficiency

Promoting Energy Saving
- Energy efficient operation
- Replacement to energy efficient equipments

Utilization of Unused Energy
- Improvement of biogas production and utilization
- Expansion of beneficial usage of small hydro power and heat energy in wastewater

Production of Natural Energy
- Expansion of solar power and wind power

Setting up the Basis for Energy Self-Sufficiency
- Planning energy self-sufficiency scheme for every treatment facilities
- R&D, education, campaign for low-carbon green growth

(Ministry of Environment, 2010)

Ⅱ Enhancing Energy Self-Sufficiency

1 Using High Efficiency Equipments

Basic Strategies

❖ Basic Strategies

- **Definition**

$$\text{Energy self-sufficiency} = \frac{(\text{Renewable Energy production} + \text{Energy saving})}{\text{Annual electric use}}$$

- **Basic Strategies to Enhance Energy Self-Sufficiency**
  - Improve renewable energy production
    : mainly, enhancing biogas production in AD
    (co-digestion of food waste or night soil can be considered)
    : introducing solar power, small hydropower, wind power, etc.
  - Focus on biggest energy consumers at WWTF (**aeration**, pumping, etc)
  - **Tailor operations** to meet seasonal and diurnal changes
  - Consider equipment life and energy usage to guide repair and replacement

Energy Saving - High Efficient Equipment

Saving Aeration Energy in Biological Process

- Oxygen Transfer Rate

$$OTR = k_L \cdot A \cdot (DO_{sat} - DO)$$
$$OTR/V = k_L \cdot (A/V) \cdot (DO_{sat} - DO)$$
$$OTR = k_L a \cdot (DO_{sat} - DO) \cdot V$$

- OTR : oxygen transfer rate (kg/h)
- k_L : mass transfer coefficient (m/h)
- $k_L a$: volumetric mass transfer coefficient (/h)
- A : interfacial area available for mass transfer (m^2)
- DO_{sat} : dissolved oxygen in water at saturation (kg O_2 m^{-3})
- DO : dissolved oxygen in water (kg O_2 m^{-3})
- V : water volume (m^3)

- k_L a is a function of the aeration system and the reactor geometry

Energy Saving - High Efficient Equipment

Saving Aeration Energy in Biological Process

- Oxygen Transfer Rate in process condition

$$\text{OTR in process condition} = \alpha k_L a \cdot (\beta DO_{sat} - DO) \cdot V$$

- α : alpha factor, or the reduction in transfer rate caused by impurities in the wastewater
- β : beta factor, or the reduction in transfer rate caused by the increased salinity of the wastewater

$$\alpha = \frac{(k_L a)_{\text{process water}}}{(k_L a)_{\text{clean water}}}$$

- The α factor accounts for contaminants in the wastewater
- Soaps, detergents have the most impact on the α factor
- The α factor is the most uncertain of the various oxygen transfer parameters and is the most difficult to accurately know.

Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

- Types of aerator

< Surface aerator >

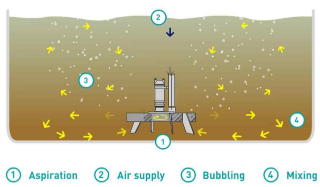
< Coarse bubble diffuser >

Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

- Types of aerator

< Fine pore diffuser >



< Turbine >

< Jets >

Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

- Aeration efficiency in various types of aerator

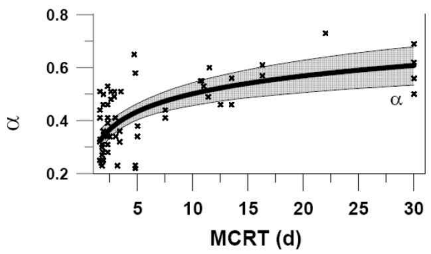
Aerator Type	SAE (kg O_2/kWh)	Low SRT AE (at 2 mg O_2/L)	High SRT AE (at 2 mg O_2/L)
High-speed surface aerator	0.9 ~ 1.3	0.4 ~ 0.8	
Low-speed surface aerator	1.5 ~ 2.1	0.7 ~ 1.5	
Coarse bubble	0.6 ~ 1.5	0.3 ~ 0.7	0.4 ~ 0.9
Turbines or jets (fine bubble)	1.2 ~ 1.8	0.4 ~ 0.6	0.6 ~ 0.8
Fine pore (fine bubble)	3.6 ~ 4.8	0.7 ~ 1.0	2.0 ~ 2.6

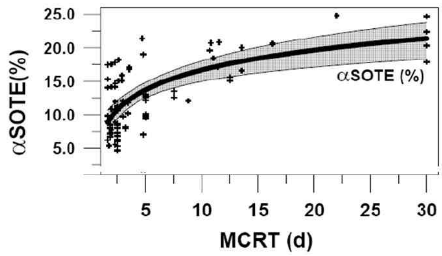
- The data in the table are supported by published tests, but there can be site-specific considerations that alter the results.
- The table results should not be used as a general guide line and not for design.
- Aeration efficiency should always be verified by transfer testing.

Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

- α Factors



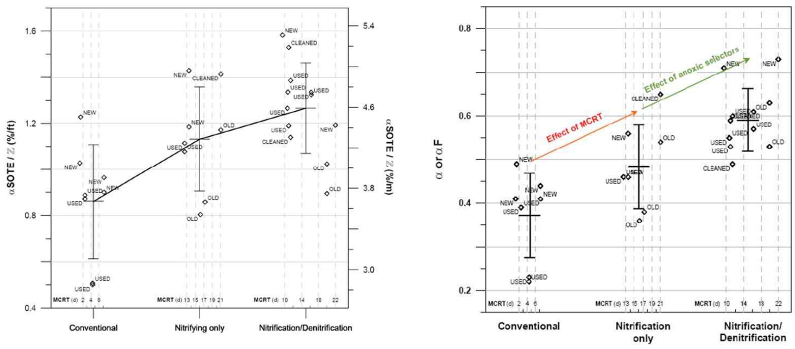


- For treatment plants operating at low MCRT, alpha factors are suppressed, and may average 0.3. At high SRT the alpha factors increase.
- The reason for the increased alpha at high MCRT is the more rapid and efficient removal of surfactants.
- In plug flow aeration tanks, the alpha factor at the influent zone of the aeration tank may be only 0.3 but at the effluent zone it may be as high as 0.8.
  → requires aeration tapering

Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

Oxygen Transfer Rate and α Factor with Different Plant Layouts



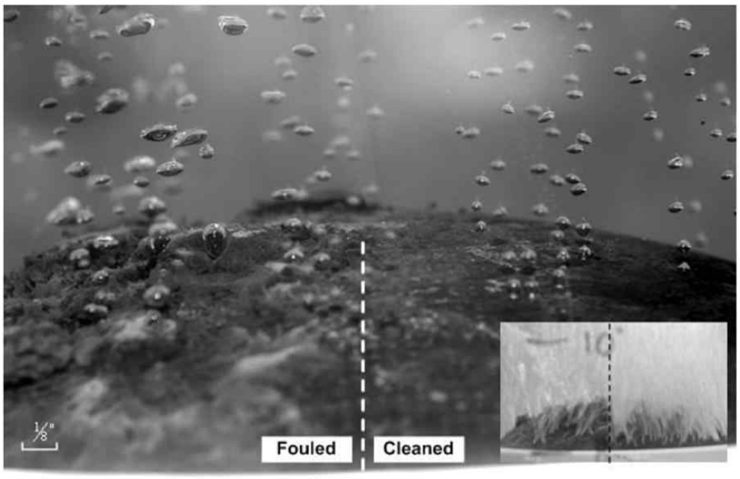
- NEW : within 1 month from installation
- USED : between 1 and 24 months of operation
- OLD : over 24 months in operation
- CLEANED : within 1 month from a cleaning event

> The effect of diffuser ageing outweighs the increase in performance due to process upgrade (from conventional to N-only and NDN).

Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

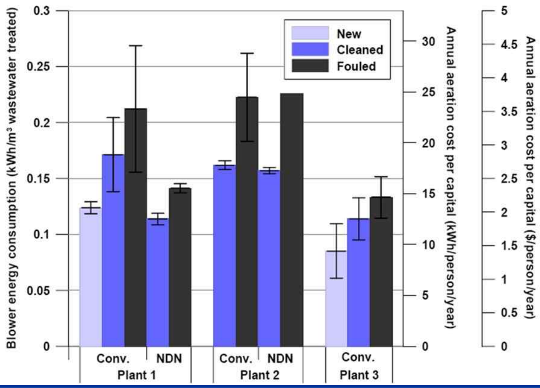
Photographic Evidence of the Effects of Diffuser Fouling



Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

- Energy Cost

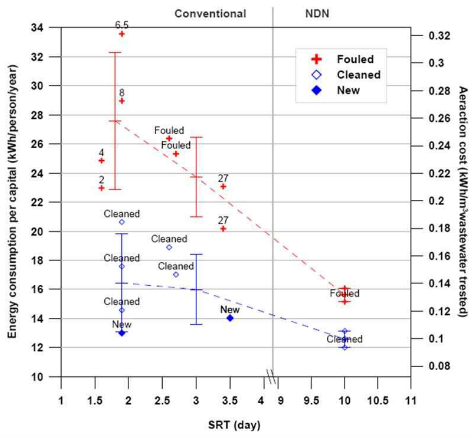


- It is important to observe that the energy consumption per cubic meter of wastewater treated did not increase, due to the improved transfer at high MCRT.
- There were significant differences in energy consumption because of fouling which were recovered with cleaning.

Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

- Energy Cost



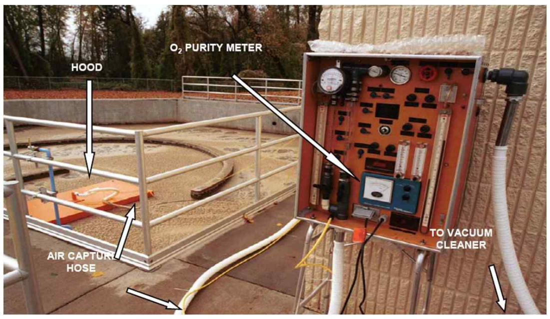
- Large difference in energy consumption for fouled and cleaned diffusers
- Operation at longer SRT is not more expensive that at lower SRT. Part of the reason is that low SRT systems foul more and more rapidly.

Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

Aerator Performance Monitoring

- Off-gas testing to determine transfer efficiency and OUR is one of the key ways to monitor system performance
- Sample diffusers, collected from aeration tanks, should be routinely analyzed for pressure drop, fouling and changes in material properties.
- System pressure should be tracked to predict when cleaning will be necessary.

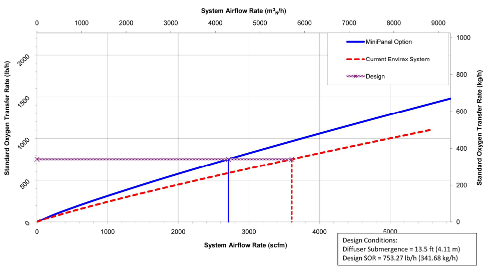


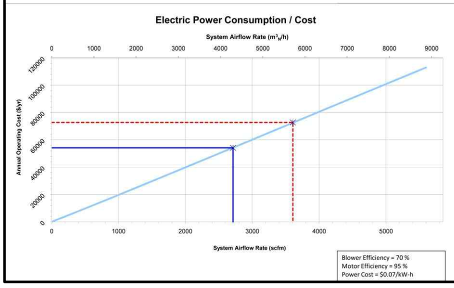
- A floating hood
  : collecting off-gas (at least 2% of the surface area should be sampled)
- The OTE can be measured using an oxygen analyzer and the air flux can be determined using the hood area and the off-gas flow rate.

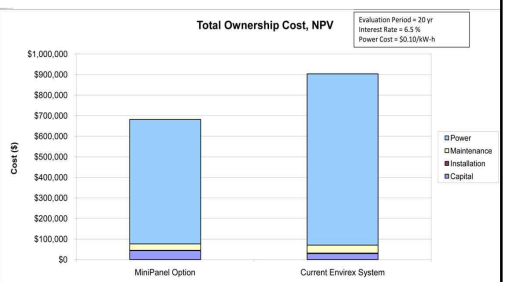
Energy Saving - High Efficient Equipment

❖ Saving Aeration Energy in Biological Process

Case Study – Allegan WWTP (US)







Energy Saving - High Efficient Equipment

Saving Mixing Energy

Pulsed Air Mixing of Anoxic and Anaerobic Zones - BioMIx

- Efficient mixing in anaerobic and anoxic zones with no significant oxygen transfer.
- Intermittent release of bursts of compressed air at the bottom of the water column zones.
- Testing at F. Wayne Hill Water Resource Center in Buford, GA to compare effectiveness, compatibility with anaerobic and anoxic environments, and power requirements vs. a conventional submersible propeller mixer.
  - Dye tracer tests showed similar mixing for the BioMIx and submersible mixer systems.
  - Continuous oxidation reduction potential (ORP) measurements over periods of 12 to 28 hours showed 95th percentile ORP values of less than -150 millivolts (mv), which is indicative of anaerobic environments.
  - Power analyzer readings taken simultaneously showed that energy (in kW) required to mix one anaerobic cell using the BioMIx system was 45 percent less than the energy required by a submersible mixer.

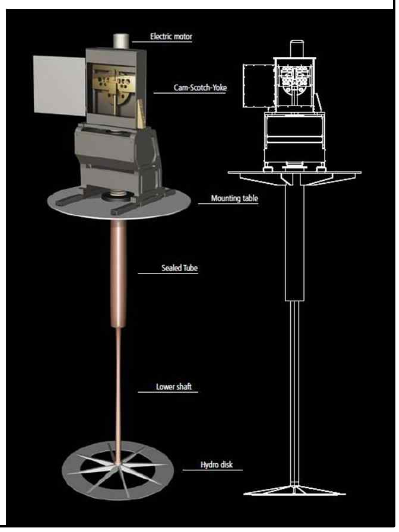
<Typical BioMIx installation>

Energy Saving - High Efficient Equipment

Saving Mixing Energy

Vertical Linear Motion Mixer

- Thin steel disk to mix digester contents.
- Effective mixing compared to conventional methods.
- Significant energy savings reported.
- Testing at Tucson, AZ in 2007 showed effective mixing at 11% of energy required by impeller draft tube mixers.



Ⅱ Enhancing Energy Self-Sufficiency

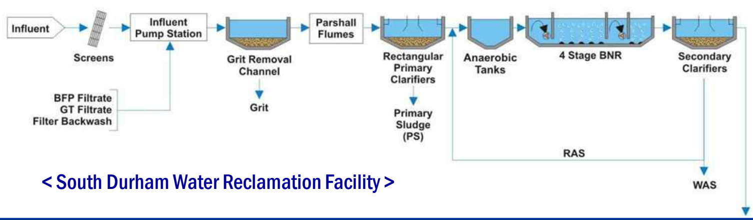
2 Tailored Operation

Energy Saving through Tailored Operation

❖ Saving Aeration Energy Using DO Control

Ammonia Based DO Control Concept

- Concept : use aerobic zone ammonia concentration to determine DO setpoint
  – Minimize airflow/energy & lowers DO return to anoxic/anaerobic zones
- Use online analyzer to measure ammonia at the last aerobic cell



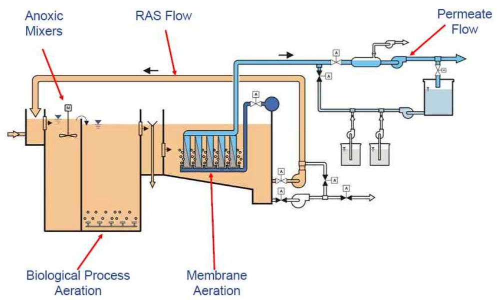
< South Durham Water Reclamation Facility >

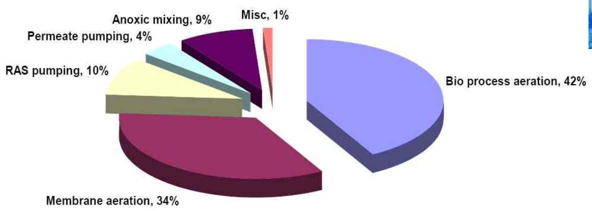
- Case Study - South Durham WRF (US)
  - Problem : Poor DO control using one air control valve for a pair of aeration tanks
  - Solution : Zone DO control. Two zones per tank
  - Capital cost : ~$500,000
  - Annual savings : ~$100,000 - $120,000 ☞ Simple Payback : 5 years

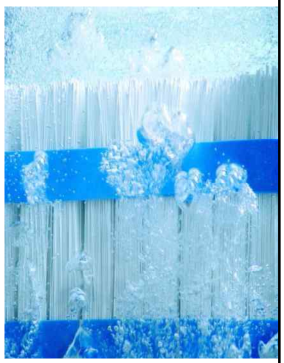
Energy Saving through Tailored Operation

❖ Saving Aeration Energy in MBR Process

- Energy User in MBR System





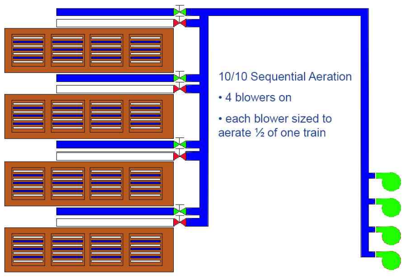


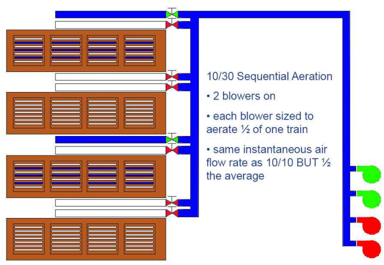
<Air scouring>

Energy Saving through Tailored Operation

❖ Strategy for Air Scouring

- 10/10 Air Scour and 10/30 Air Scour (GE, Zenon)





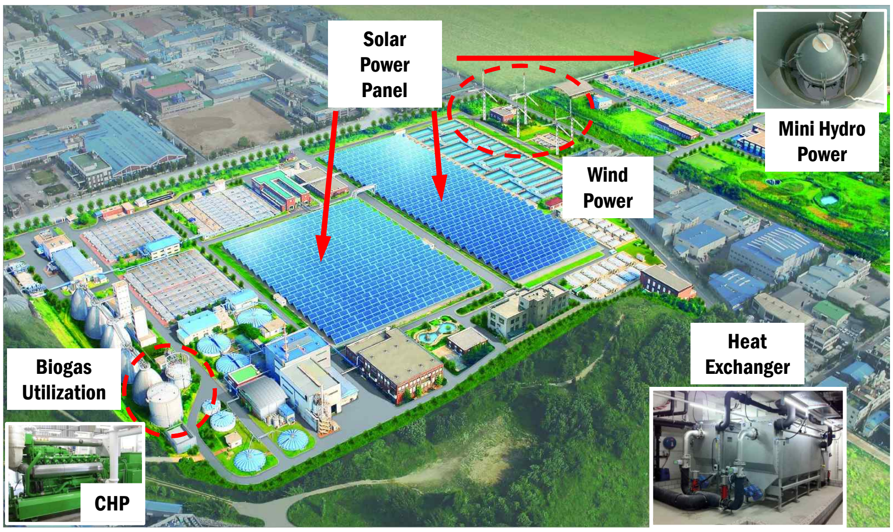
- 10/10 air scour : cycled air on and off in 10 second intervals
- 10/30 air scour
  - for 10 seconds, 24 of the 48 modules in a given cassette receive air scour. For the next 10 seconds this cassette does not receive air scour, but air scour is being used in other cassettes. For the next 10 seconds, the other 24 modules in the cassette receive air scour. For the last 10 seconds of the cycle, the cassettes do not receive air scour. A given cassette receives air ½ the time, and a given module receives air ¼ of the time. 50% savings compared to 10/10.
- Maintain 10/10 aeration at or above average daily flow
- Run at 10/30 aeration below average daily flow

Ⅱ Enhancing Energy Self-Sufficiency

③ Utilize Unused Energy Source

Unused Energy Sources in WWTP

❖ Enhancement of Energy Self-Sufficiency in Ansan WWTF, Korea



Hydraulic Energy

❖ Mini Hydro Power

Advantages and Disadvantages

- Advantages:
  - Low maintenance costs
  - Mature technology
  - Installation in a pipeline or outfall
- Disadvantages:
  - Power output is dependent on elevation changes
  - Limited availability in small sizes

Bucheon WWTP

- Capacity : 55 kW x 2
- Elevation change : 3.4 m

Biogas

❖ Current Status of Anaerobic Digester in Korea

- Number of sewage treatment facilities : 566 (in 2013)
  (Facilities with capacity lower than 500 m^3/day are not included)
- Total amounts of sewage treated in facilities : 25.4 million m^3/day
- 65 facilities have anaerobic digester, but only 57 facilities operate digesters actively
- Anaerobic digestion (AD) efficiency is quite lower than that in other countries

❖ AD Efficiency and Sludge Reduction Data in Some Facilities in Korea

Facility	Anaerobic Digester Volume (m^3)	Digestion Efficiency (%)	Sludge Reduction (%)
A	82,776	35.3	27.3
B	17,500	37.3	14.4
C	25,120	25.1	35.9
D	7,234	47.3	68.0
E	7,551	23.8	44.2
F	12,565	42.3	29.1
G	2,154	50.3	30.7

Note) $\text{Anaerobic Digestion Efficiency} = \left(1 - \frac{FS_{in} \times VS_{out}}{FS_{out} \times VS_{in}}\right) \times 100$

Increase Biogas Production via Pretreatment

❖ What Can We Expect from Pretreatment Before Anaerobic Digestion

- Faster hydrolysis of particulate
- Decrease of retention time in anaerobic digestion
- Enhancement of biogas production
- Improvement of dewatering characteristic of sludge

❖ Types of Pretreatment Methods

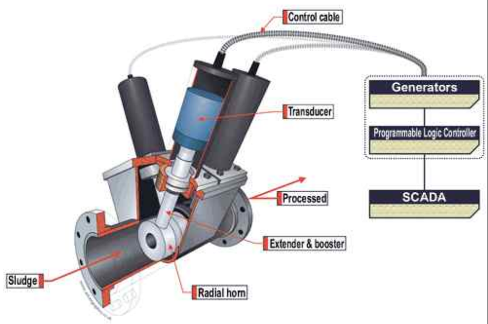
- Mechanical : homogenizer, stirred ball mills, **cavitation**, etc.
- Chemical : alkaline/acid hydrolysis, ozonation
- Biological : enzyme addition, thermophilic bacteria injection, etc.
- Thermal : **thermal hydrolysis** & Freeze-Thawing
- Combined : thermal-chemical, ultrasonic-chemical, etc.
- Others : electron beam, microwave, **focused pulsed electricity** etc.

Ultrasonic Pretreatment

❖ Commercial Process - Sonix

Description

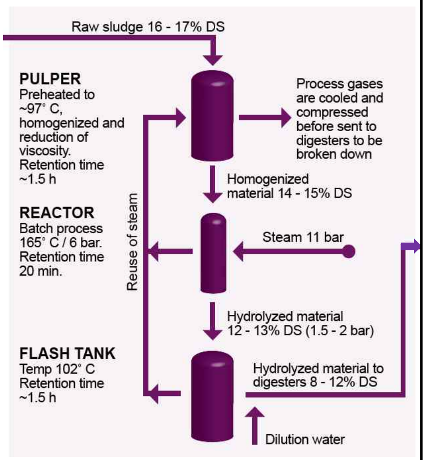
- English company, Sonico
- Usually 3 to 5 sonotrodes are installed in 1 unit (6kW/unit)
- VS reduction and gas production increase by up to 30 ~ 50%



Thermal Pretreatment

❖ Commercial Process - Cambi Process

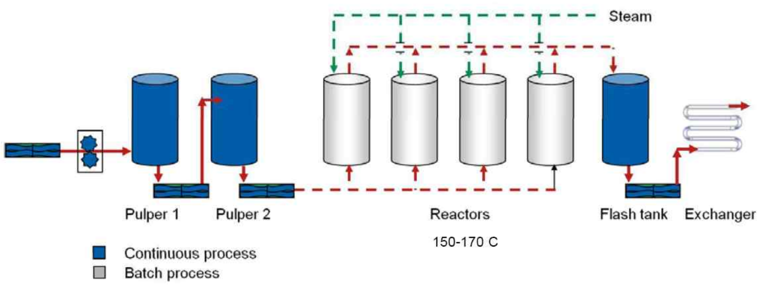
- Description
  - Norwegian company, Cambi
  - First full scale demonstration plant
    : HIAS WWTP in Hamar, Norway
  - Using high-pressure steam : 6 bar, 165°C
  - Process configuration
    : Pulper – Reactor – Flash Tank
  - Batch process
  - Need pre-dewatering process
    : TS contents 16 ~ 17%
  - Increase gas production up to 30 ~ 100%



Thermal Pretreatment

❖ Commercial Process - Cambi Process

- Operation



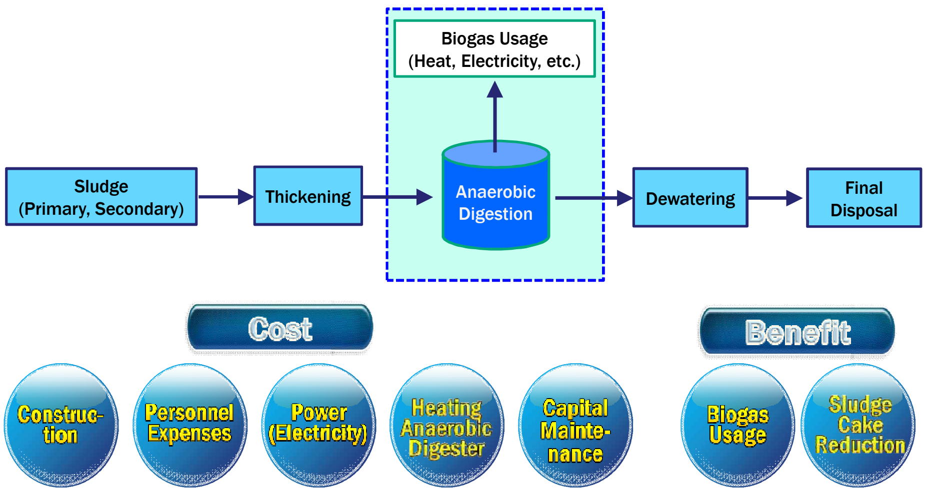
	15 min	15 min	30 min		15 min	15 min
Reactor 1	Fill	Steam In	React		Steam out	Empty
Reactor 2	Empty	Fill	Steam In	React		Steam out
Reactor 3	Steam out	Empty	Fill	Steam In	React	

Supplementary

Should I Install the Anaerobic Digester in My WWTF?

Cost Benefit Analysis of AD Installation

- Cost Benefit Analysis Boundary



Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Criteia

Benefit/Cost Ratio (B/C ratio)

$$B/C = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} / \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

- t : time
- n : period, 20 years for sludge treatment facility
- r : discount rate (5.5%)
- Present value of project benefits / present value of project costs
- If B/C ≥ 1.0, the project is judged to be worthwhile in economic terms

Calculation of B/C ratio

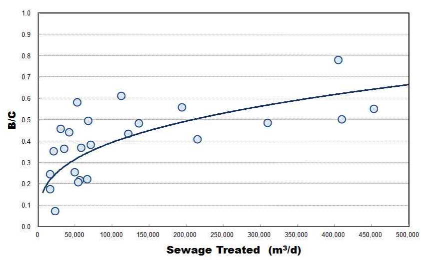
Period	Cost						Benefit		
	Construction (million won)	Personnel Expenses (thousand won/year)	Electricity (thousand won/year)	Heating Energy (thousand won/year)	Maintenance (thousand won/year)	Sum (million won)	Biogas Usage (thousand won/year)	Sludge Cake Reduction (thousand won/year)	Sum (million won)
1	17,944	52,718	73,075	272,583	50,402		625,856	219,612	
2		49,970	69,265	258,373	47,774		593,228	208,163	
3		47,365	65,654	244,903	45,283		562,302	197,311	
.		.	.	.	.		.	.	
.		.	.	.	.		.	.	
.		.	.	.	.		.	.	
19		20,110	27,875	103,981	19,227		238,743	83,774	
20		19,062	26,422	98,560	18,224		226,296	79,407	
	17,944	664,654	921,300	3,436,638	635,447	23,602	7,890,575	2,768,791	10,659

- B/C ratio = 23,602/5,676 = 0.45

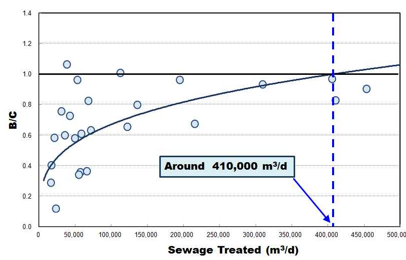
Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

Effect of Digestion Efficiency



<Digestion Efficiency 27%>



<Digestion Efficiency 45%>

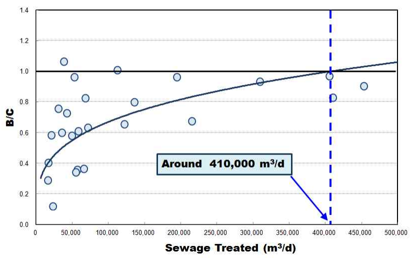
Note) 27% is average digestion efficiencies of 24 sewage treatment facilities in Korea

- At 27% of digestion efficiency, there was no facility with B/C ratio over 1.0.
- At 45% of digestion efficiency, B/C ratio exceeds 1.0 at wastewater treatment capacity over 410,000 m^3/d.
- Increase in digestion efficiency raise B/C ratio due to the biogas production increase and reduction in sludge cake production.

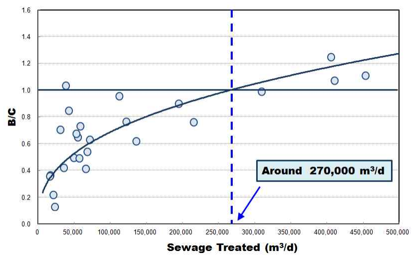
Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

Effect of Final Disposal Cost



<Using individual final disposal cost>



<Using average final disposal cost>

Note 1) Anaerobic digestion efficiency was assumed to be 45% at all treatment facilities

Note 2) Final disposal cost

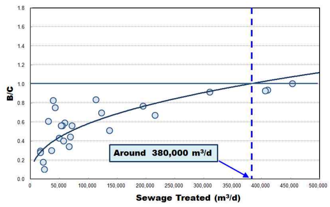
Carbonization	: 116,000 won/cake ton	Incineration	: 87,000 won/cake ton
Drying	: 100,000 won/cake ton	Solidification	: 63,000 won/cake ton
Average	: 91,000 won/cake ton		

- With average final disposal cost, the treatment capacity with B/C ratio 1.0 reduces to 270,000 m^3/d.
- Final disposal cost largely affects on B/C.

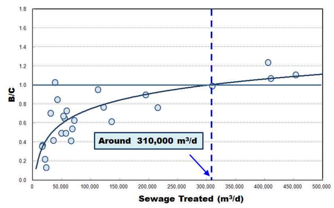
Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

Effect of Final Disposal Methods



<Solidification>



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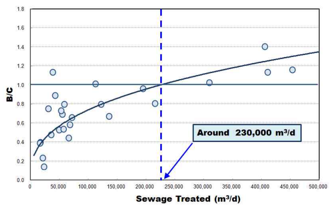
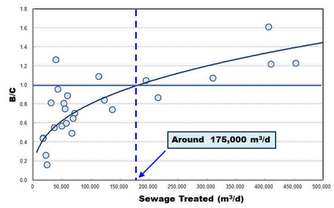


<Drying>



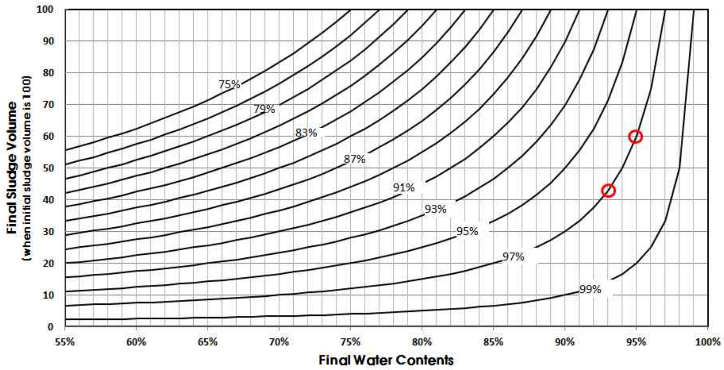
<Carbonization>

- AD installation is more economical at the facility using carbonization as the final sludge disposal option.

Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

Effect of Sludge Thickening before AD

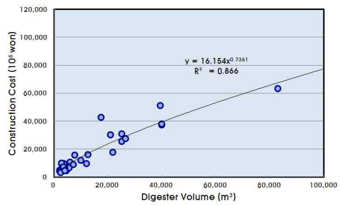


- Average water contents (W.C) of influent sludge is about 97%.
- If W.C of sludge is reduced to 95% or 93%, the volume of sludge will be 60% or 42% of initial sludge volume, respectively. → We can build smaller anaerobic digester

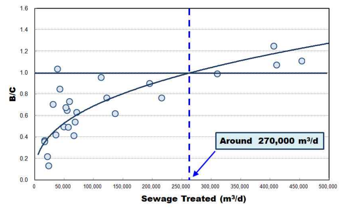
Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

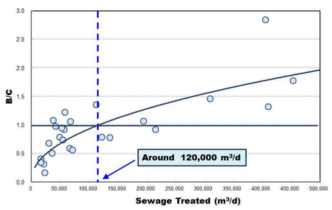
Effect of Sludge Thickening before AD



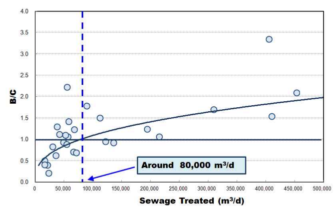
<AD construction cost vs AD volume>



<Water Content : 97%>



<Water Content : 95%>



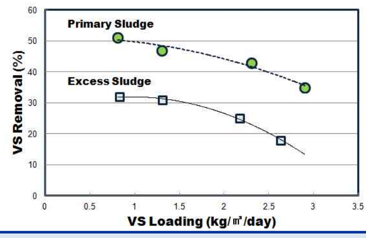
<Water Content : 93%>

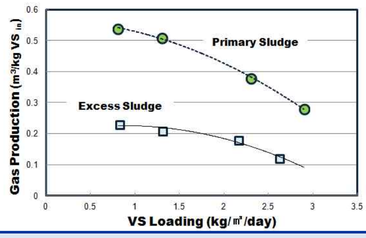
- Higher solids contents leads to smaller capacity reaching B/C = 1.0 due to the lower construction cost.

Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

- Effect of Sludge Thickening on VS Removal





- Higher VS loading can deteriorate anaerobic digestion efficiency.

❖ Some Findings from Cost Benefit Analysis Results

- There's specific anaerobic digestion capacity that can achieve economical benefit under given operational condition.
- If you want to gain economical benefit with smaller anaerobic digester (i.e. lower initial investment), mainly consider the measures to increase solids contents in sludge and anaerobic digestion efficiency.

Thank You for Your Attention!

Questions or Comments ?

hjkim@jiuene.com