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Enhancing Anaerobic Digestion of High-solid Sludge with Coupled Ultrasonic and Alkaline Pretreatment: Mechanism Research and a Full-Scale Experiment

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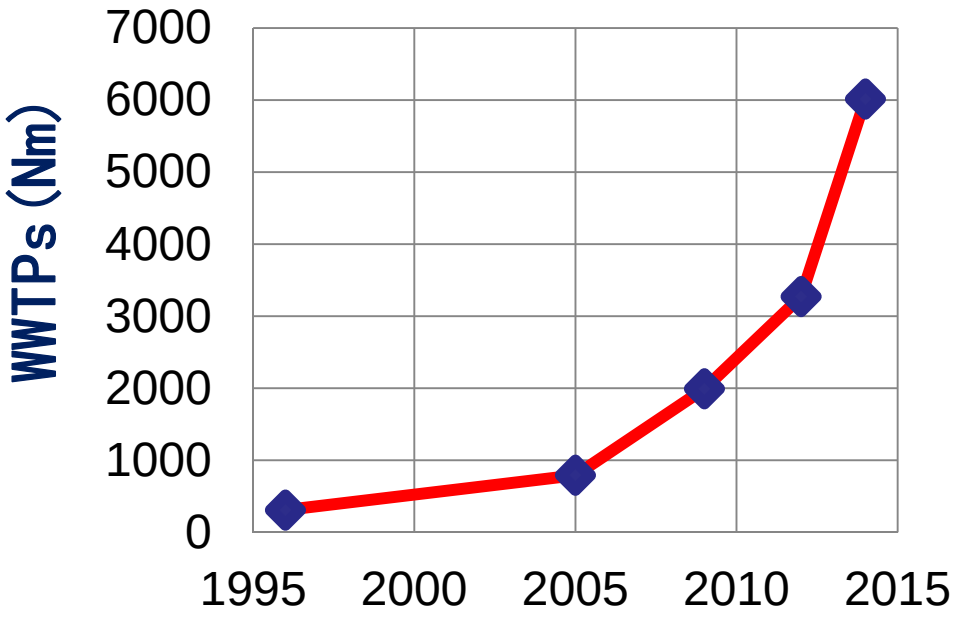
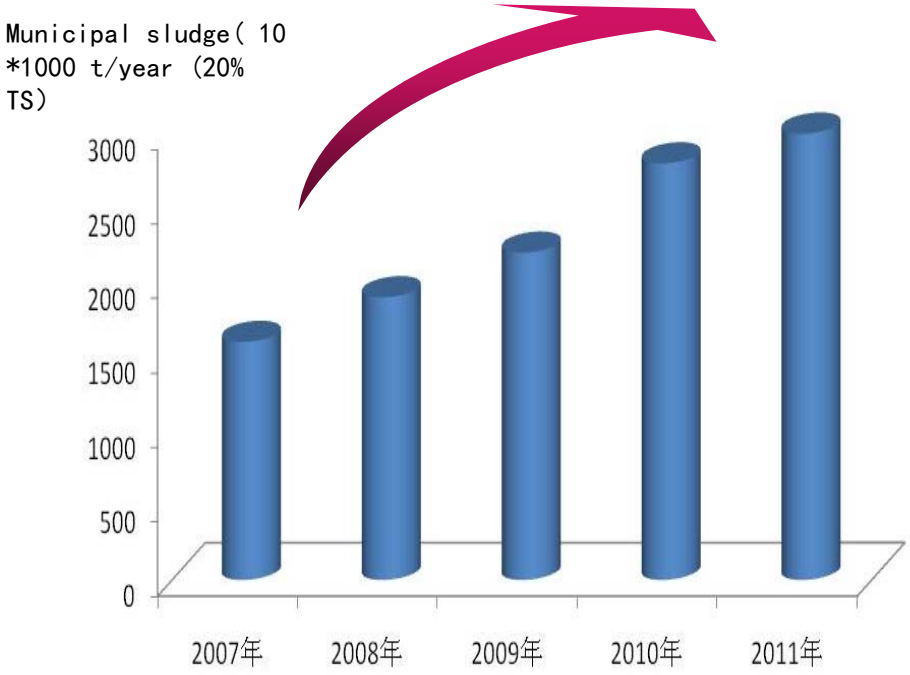
The problems and challenges of sludge in China



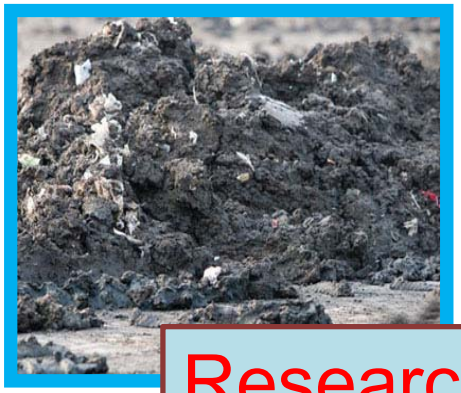
A fast-growing sewage plants

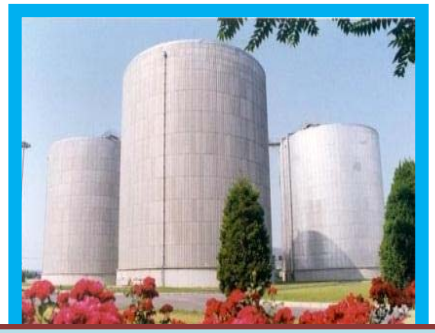


Sludge production from WWTPs

It is predicted that sludge production will reach more than 80 million tons (20% TS) in 2020。

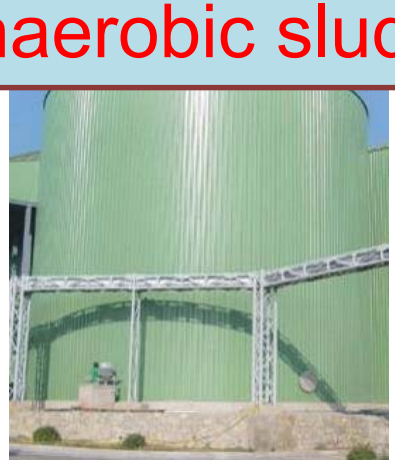
Background

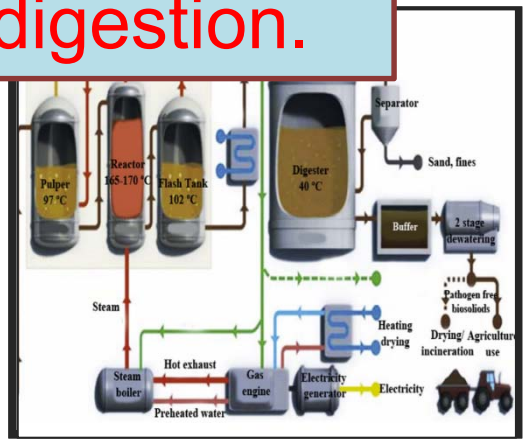




Research on high efficiency anaerobic digestion technology is the current hotspot of anaerobic sludge digestion.

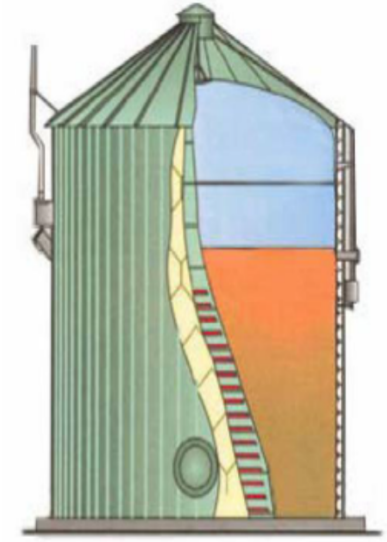
Sewa ... overy





Traditional AD → High Solid Concentration AD → **Pretreatment-High Solid AD**

High-solid anaerobic digestor



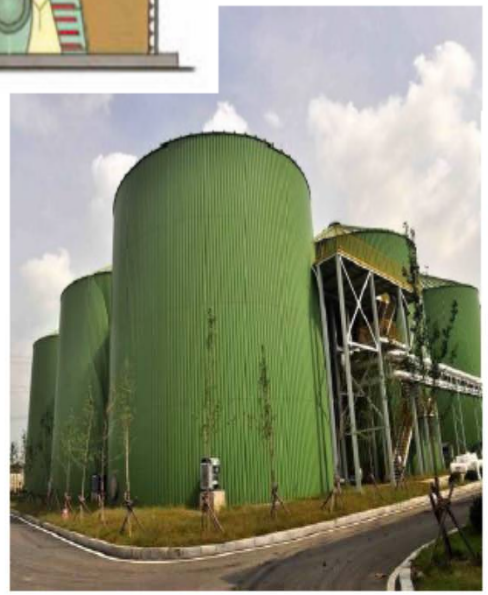
TS: from 5 %TS upgrading to10% TS

Save 50% of the digester volume

Reduce heat loss by 50%

Save 50% space

To compare with traditional anaerobic digestion



1）采用钢结构

2

3）单池池容较小

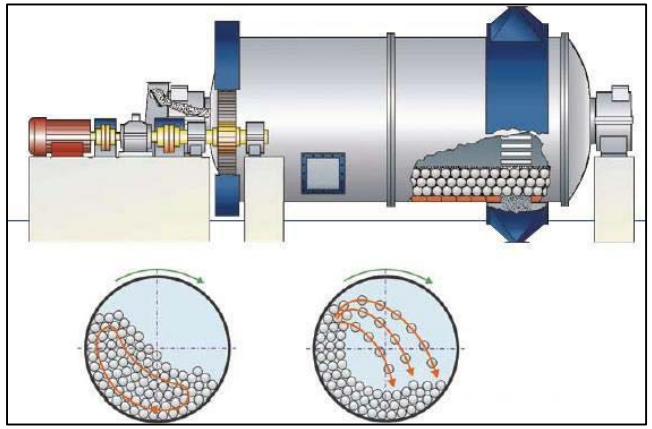
Drawbacks:

High Mass transfer resistance

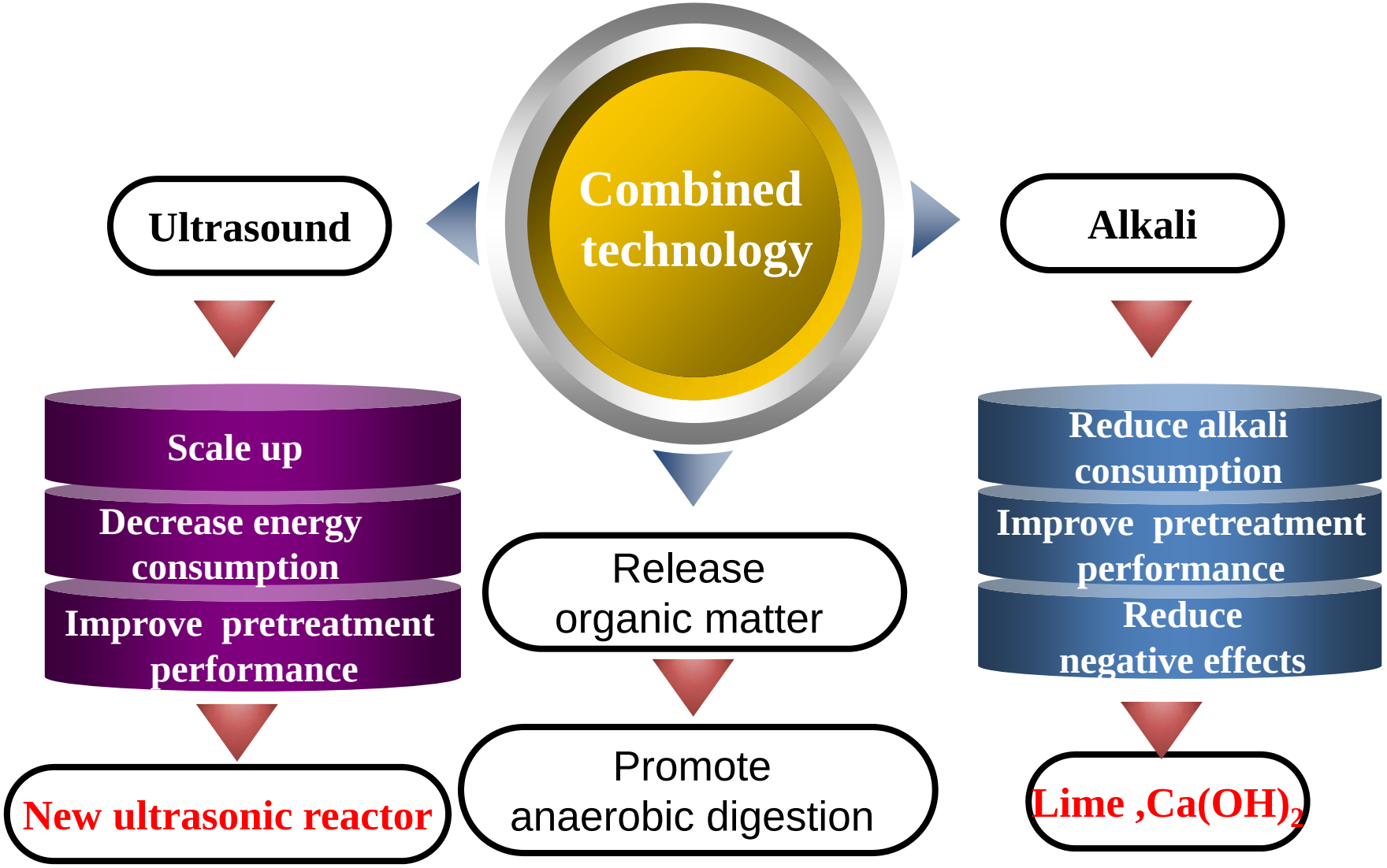
In order to upgrading biogas production of AD , sludge hydrolysis rate should be improved

Sludge pretreatment technologies for high efficiency anaerobic digestion

- Thermal hydrolysis
- Mechanical grinding
- Ozone oxidation
- Ultrasonic pretreatment
- Alkali pretreatment



Characteristics of combined ultrasound and alkaline pretreatment technology

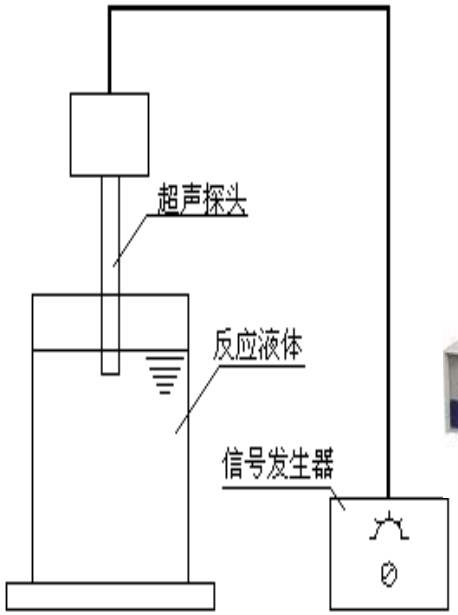


Contents of this study

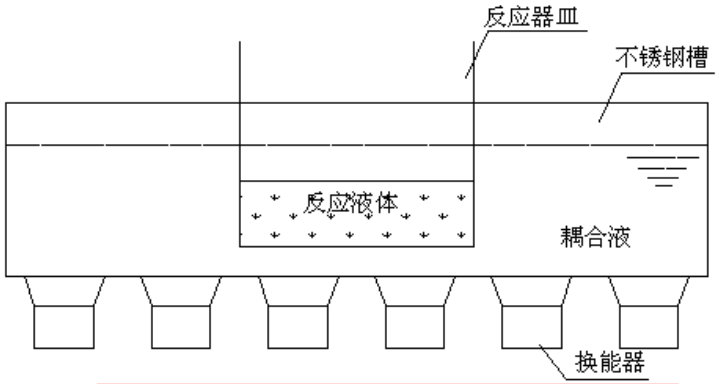
1. Development of less energy ultrasonic equipment for sludge disintegration
2. Study on coupled ultrasonic and alkaline pretreatment technology
3. **Optimization of technological parameters and cost analysis in full-scale experiment**

Classification of ultrasonic reactors

Probe ultrasonic reactor



Chamber ultrasonic reactor



➢**The probe is directly immersed in the reaction liquid in a probe ultrasonic reactor.**

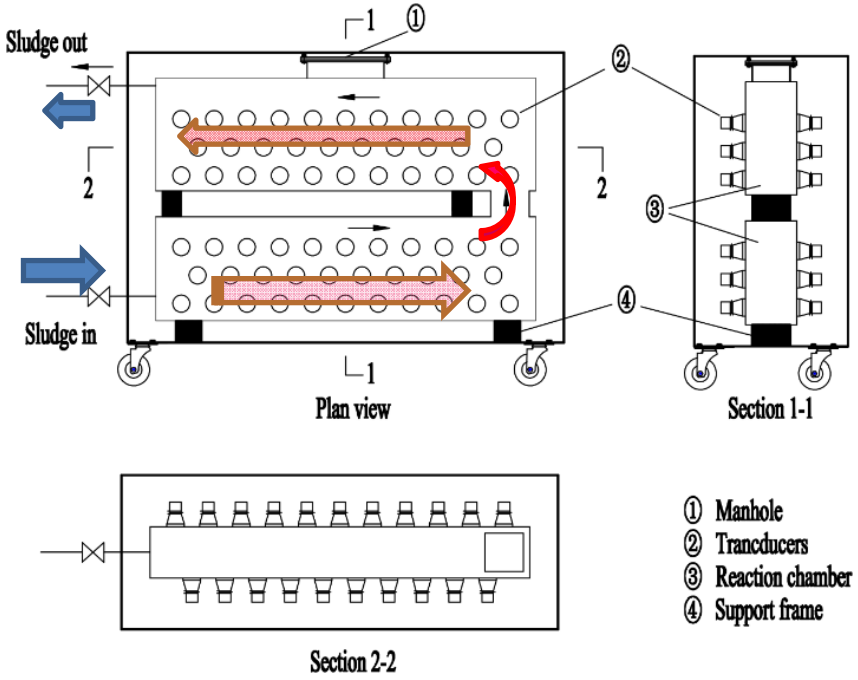
➢**The reaction liquid can be put into the tank in a chamber ultrasonic reactor. The probe does not contact with the liquid.**

Comparison of probe and chamber ultrasonic reactors

Parameters	Probe reactor	Chamber reactor
Number of transducer	Less	More
Ultrasonic power	Strong	Weak
Uniform distribution of sound field	Weak	Strong
Radiant region	Small	Large
Long-term stability	The probe is easy to be damaged	Attenuation of power occurs
Equipment corrosion	Strong	Weak
Energy consumption	High	Low
Energy utilization efficiency	Low	High
Feasibility of full scale application	Low	High

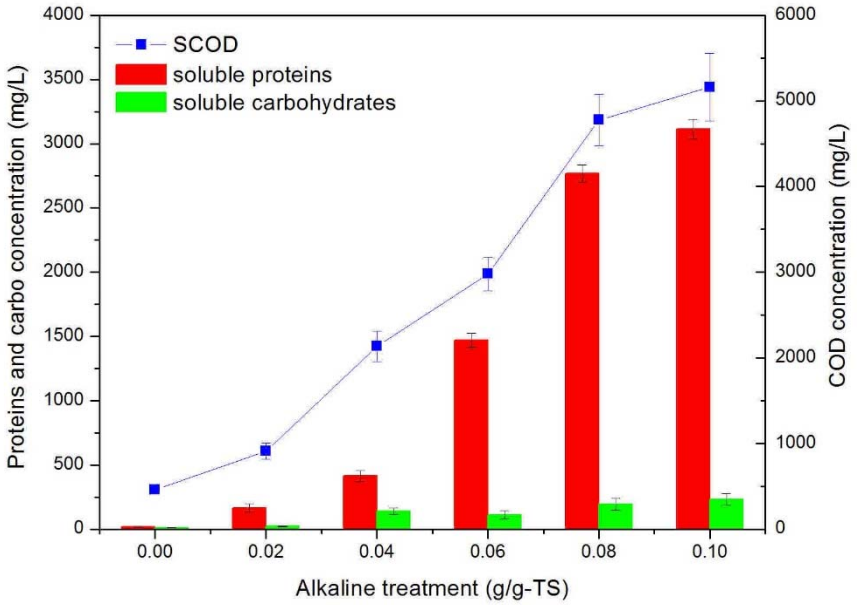
The chamber reactor has a wide range of disintegration, high energy utilization efficiency and low equipment consumption, and is suitable for full scale application.
In the multi probe ultrasonic reactor, a reasonable arrangement of probes, such as contralateral arrangement, can form standing waves, effectively expanding the degree of ultrasonic disintegration

Development of dense multi probe chamber ultrasonic sludge disintegration reactor

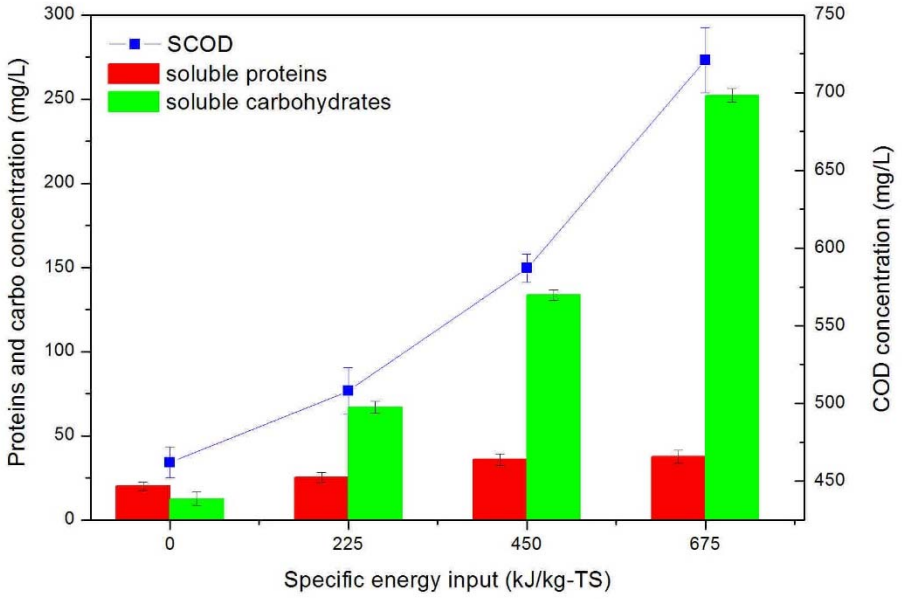


Power: 5kW (0-100% adjustable)
Frequency: 20kH
Volume: 250L
Capacity: 5m^3/h
Retention time: 2-5 min
Operation mode: Two reactors in series operation

Different disintegration effects of alkaline and ultrasonic pretreatments



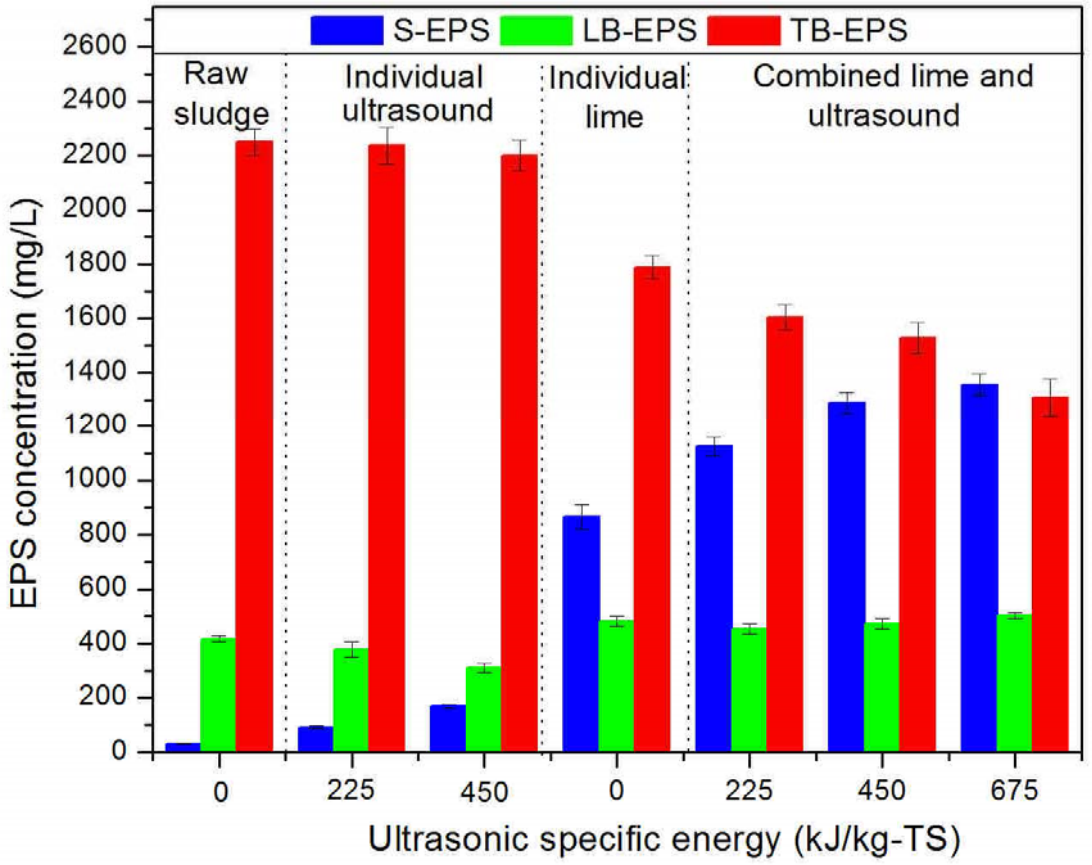
Effects of alkaline pretreatment on sludge dissolution



Effects of ultrasonic pretreatment on sludge dissolution

- **The soluble SCOD and protein increased with the alkaline amount, but the carbohydrates dissolution was limited.**
- **Less SCOD and carbohydrates were dissolved by sole ultrasonic pretreatment, but the protein dissolution was very limited.**

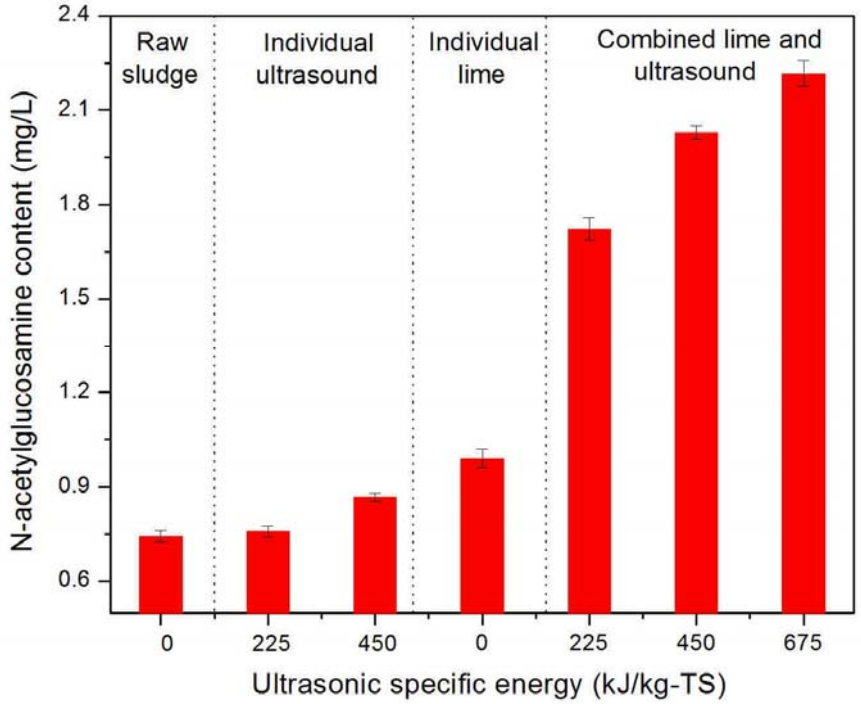
EPS disintegration by Coupled Ultrasonic and Alkaline Pretreatment



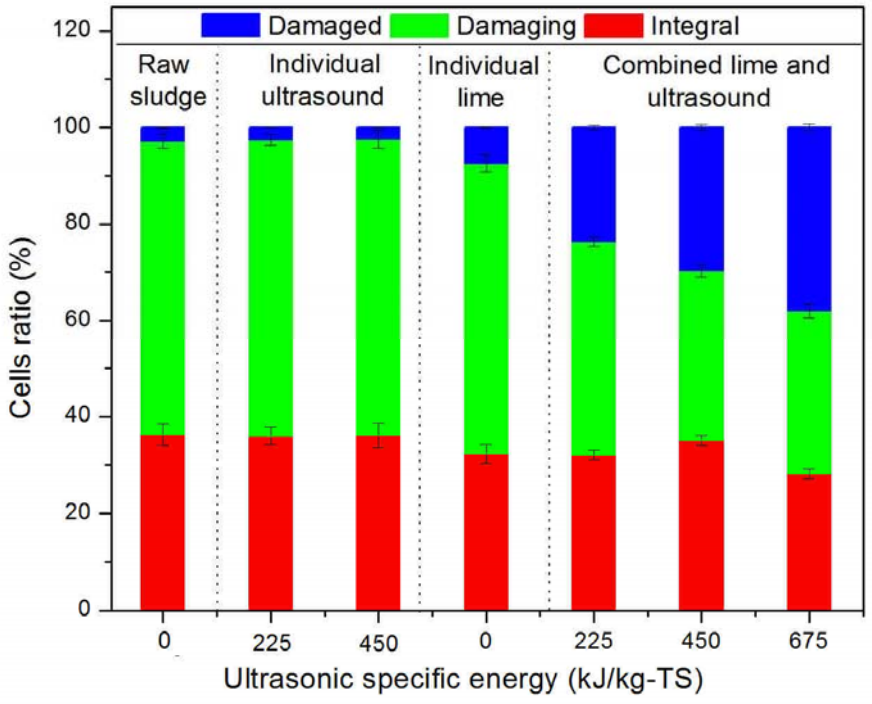
S-EPS: soluble EPS;
LB-EPS:Loose bind EPS;
TB-EPS:Tight bind EPS

- **EPS disintegration was not obvious under sole ultrasonic pretreatment.**
- **The disintegration degree was higher in coupled ultrasonic and alkaline pretreatment, compared to sole alkaline pretreatment.**

Destruction of cell structure by coupled Ultrasound and alkaline pretreatment



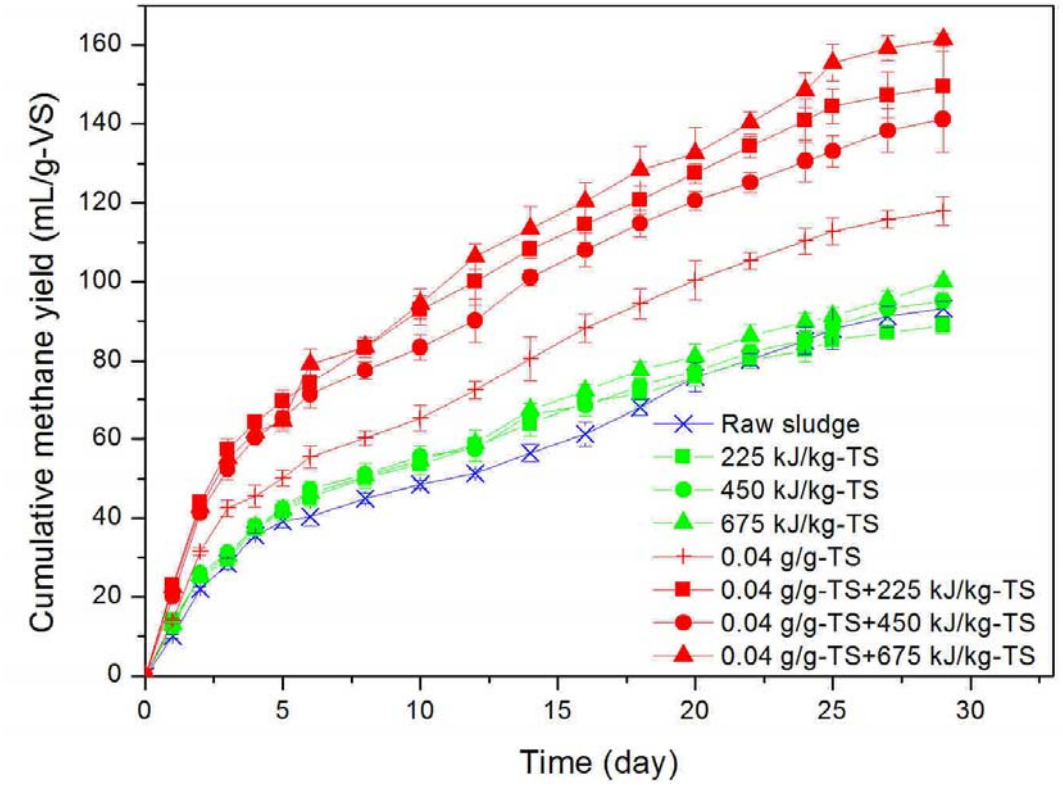
Destruction of cell wall structure



Destruction of cell membrane structure

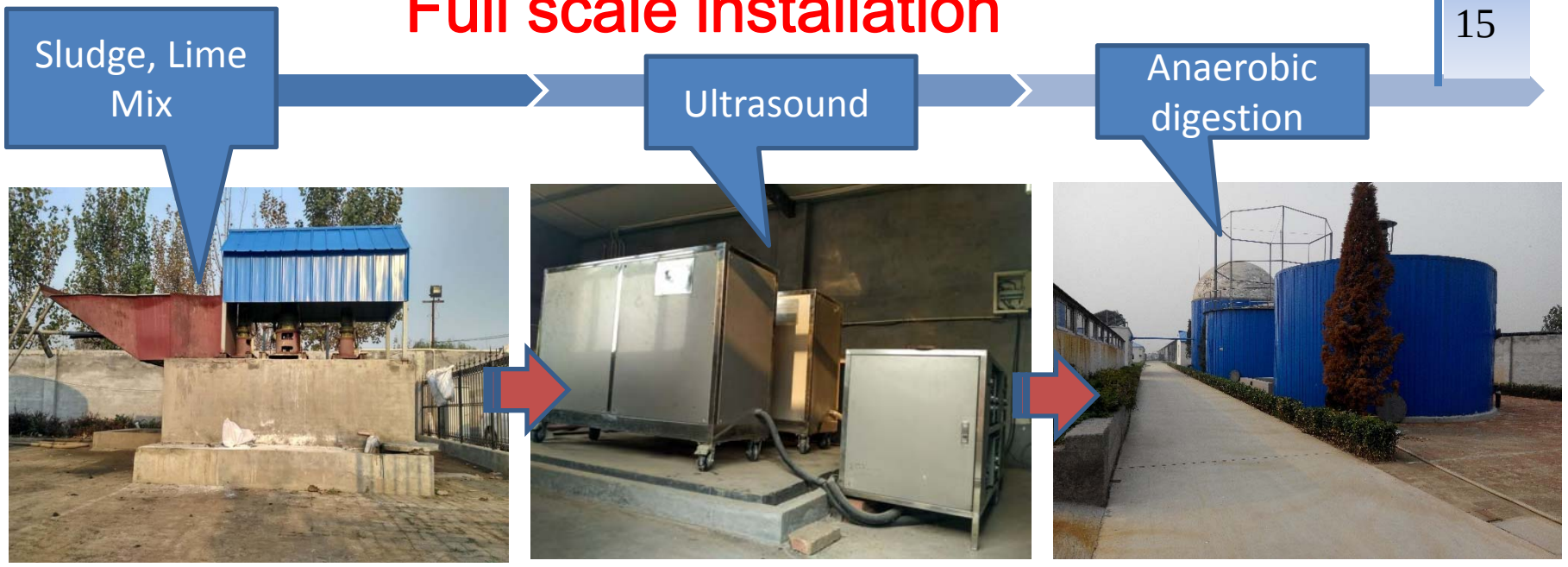
Sole ultrasonic or alkaline pretreatment had little effect on the break of cell wall and cell membrane. The coupled method had obvious disintegration effect on cell wall and cell membrane.

Effects of coupled ultrasonic and alkaline pretreatment on methane production



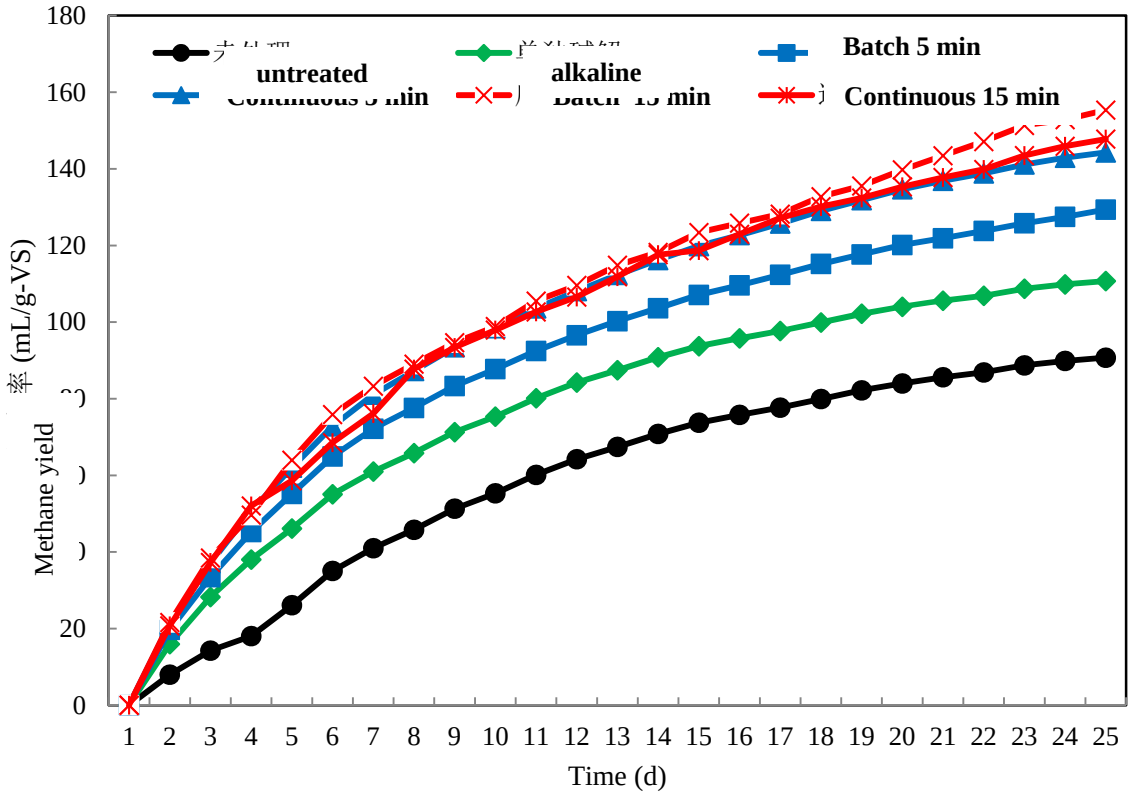
The effect of low power ultrasound on methane production was not obvious, and the methane yield increased by 50%-70% after coupled ultrasonic and alkaline pretreatment.

Full scale installation



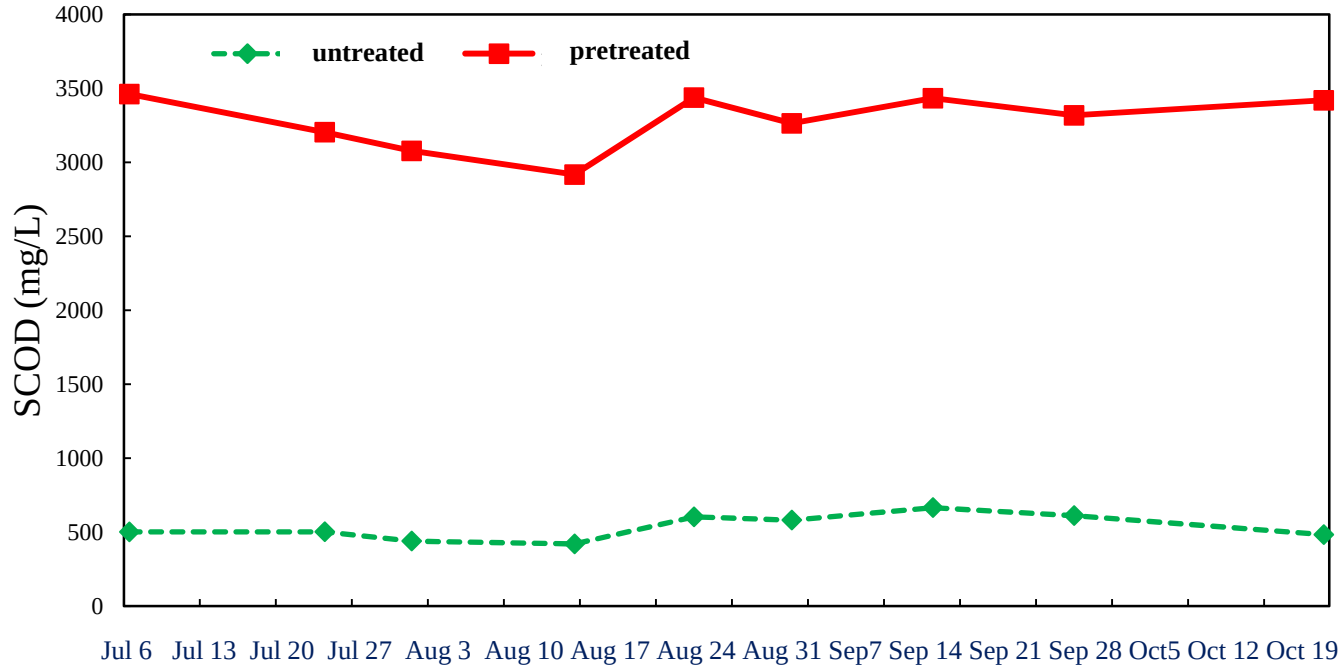
- **Raw sludge**：**dewatered sludge (TS=16%-22%，VS/TS=44%-60%)**
- **Pretreatment process**：**The raw sludge was diluted to 8%-10% of TS, mixed for 1h after alkaline addition, and then was pumped into the continuously operated ultrasonic reactors. The flow rate of ultrasonic reactors was 5m^3/h, and the HRT was 2-5min.**
- **Process scale**：**200m^3 CSTR anaerobic digester，Effective volume was about 150m^3, and daily feeding was 10m^3 of pretreated sludge.**

Optimization of ultrasonic operation mode



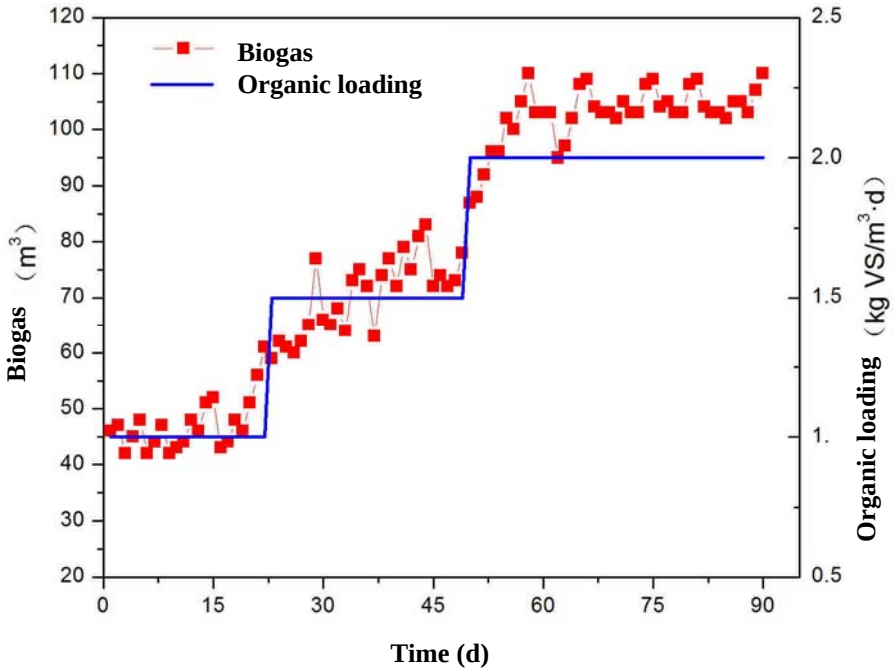
➢**Compared with the untreated group, the ultrasonic coupled alkaline pretreatment can effectively increase the methane yield.**

Stability investigation —dissolution performance (SCOD increase)

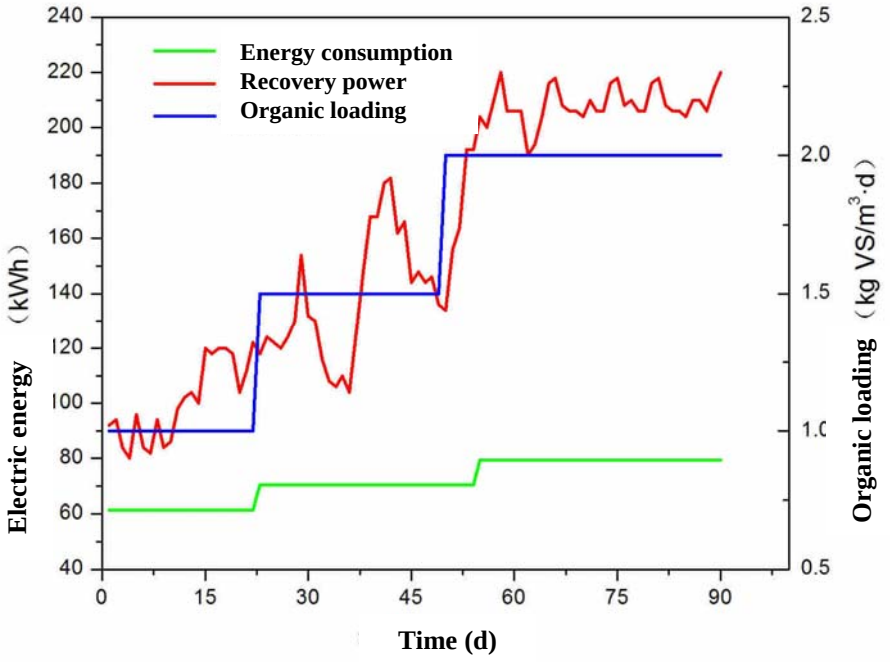


During the operation period, compared with the SCOD of 500mg/L in untreated sludge, the concentration of SCOD was stable in the range of 3000-3500mg/L after pretreatment, indicating that the operation of the equipment was good and the performance was stable.

Economic analysis of the full scale demonstration



Biogas production and organic loading



Energy consumption and organic loading

- **Biogas production increased with organic loading. When organic loading was 2kg VS/m³·d, daily biogas production was 100-110 m³.**
- **The highest daily energy consumption was 65kWh, and the daily recovery power through biogas production was equivalent to 200-220kWh.**
- **During the operation, the recovery energy was higher than the system energy consumption, which proves that the economy of the process is feasible.**

Economic analysis of the full scale demonstration

Comparison of energy consumption and production for untreated and pretreated sludge during anaerobic digestion

Sludge (t/d)	Energy consumption of ultrasonic process（kWh/d）	Energy production（kWh/d）		Net energy production（kWh/d）		Extra energy production by pretreatment（kWh/t)
		Pretreated sludge	Untreated sludge	Pretreated sludge	Untreated sludge	
5	10	92	61.3	30.5	9.8	4.1
7.5	15	118	78.7	47.5	23.2	3.2
10	20	204	136.0	124.5	76.5	4.8

Under the treatment loads of 5-10 t/d, the extra energy production of the anaerobic digestion system with pretreatment process was 3.2-4.8 kWh/t, indicating that the ultrasonic pretreatment can provide additional energy harvest.

Comparison of ultrasonic equipments for sludge pretreatment

No.	Type of reactor	Volume	Power（kW）	Sludge Conc.（g/L）	Scale	Production company
1	Probe	4 L	16	90	Lab-scale	Sonico Ltd. UK
2	Probe	29 L	10	80	Full-scale	Ultra WAVES GmbH
3	Probe	4-5 L	8	100	Lab-scale	IWE Tec GmbH
4	Probe	3.5 L	6	20-40	Lab-scale	Ulu Pandan Water Reclamation Plant, Singapore
5	Probe	1-30 L	2-48	<100	Full-scale	IWE Tec GmbH
6	Chamber	7.5 L	0.9	-	Lab-scale	Gogate et al.
7	Chamber	25 L	0.6	-	Full-scale	Sonico Ltd.
This study	Chamber	240L	10	80	Full-scale	Tianjin university

- Currently, most applications of ultrasonic reactors is the probe ultrasonic reactor. And the scale of the reactor is small and the treatment capacity is limited.
- There are still few applications of the chamber ultrasonic reactor in the world.

Comparison of energy consumption with other Full-scale pretreatment technologies

Pretreatment method	No.	Energy consumption (kWh/m^3)	Theoretical biogas increase requirement for energy consumption (%)
ultrasonic	1	6.4	14.8
	2	10	18.6
Pulse static electricity	3	16	49.5
	4	15	55.7
High pressure homogenization	5	53.6	187.6
	6	40	123.7
Ball grinder	7	21	59.9
Centrifugal breaking	8	12	34.3
	9	4.2	11.1
Thermal hydrolysis	10	61	146.7
	11	115.5	50.5
	12	152	66.5
	13	49.5	29.8
Thermal hydrolysis combined with	14	10.2	8.7
heat and power cogeneration	15	6.4	2.3
	16	5	2.6
Ultrasonic in this study	17	2	10

Compared with various pretreatment techniques in literature, the energy consumption of the ultrasonic reactor in this study is relatively lower. In order to achieve the theoretical energy consumption balance, the biogas production after pretreatment should be increased by 10%. Actually, in this study, the biogas production increased by 50%.

Summary

- **A full scale multi probe and low power chamber ultrasonic reactor with full scale has been developed.**
- **The synergistic effect of ultrasonic coupled alkaline solution can increase the disintegration degree of sludge and improve the energy efficiency of anaerobic digestion.**
- **The anaerobic digestion system with the ultrasonic coupled alkaline pretreatment system has a more net energy production.**

Challenges and Future research planning

- **The product of ultrasonic treatment equipment .**
- **Reduce energy consumption and reaction time further.**
- **Applying to the actual sewage plants.**
- ***(It might be a viable option for the sludge treatment of middle or small wastewater treatment plant, as well as WWTPs in islands*)**

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THANK YOU

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