Master Thesis

Applying anaerobic digestion for onsite treatment of domestic wastewater and biowaste at low temperature in Finland -- considering the Chinese experiences

Meng Wang

Dec. 2009

Renewable Energy Programme
The Environmental Science and Technology Division
Department of Biological and Environmental Science
Faculty of Mathematics and Science
University of Jyväskylä

Acknowledgment

This thesis could not be finished without the invaluable help and cooperation from several persons.

First of all, I would like to give my most heartful thanks to my supervisors, Prof. Jukka Rintala and Dr. Prasad Kaparaju for your valuable directions and Mr. Hannu Hoviniemi for your generous support. I feel very grateful to Dr. Prasad Kaparaju for your arrangement of the assays and professional academic advices. I also would like to thank Dr. Jussi Maunuksela for being my inspector and your wonderful lectures that I have taken during my studies. I would like to thank Mervi Koistinen for your help to my laboratory work. My deepest gratitude is given to GAIA OY and CAREI platform for their supports and people who work there: Tang Xiaona, Urop Huuskonen, Harriet Lonka and Ren Yanxiao. Thanks are also given to Mr. Hannu Haimi for his help in data collections. I am also grateful to all my classmates and friends in Finland, sorry I can not mention all your names here or this thesis will be a mile long. You have given me a lot of help and encouragement. Finally, I extend my heartfelt gratitude to my parents for their love, blessings, encouragement, and support.

Meng Wang

17. Dec. 2009

Jyväskylä

Department of Biological and Environmental Science
Faculty of Mathematics and Science
University of Jyväskylä

WANG, MENG: Applying Anaerobic Digestion for Onsite Treatment of Domestic Wastewater and Biowaste at Low Temperature in Finland -- Considering the Chinese Experiences

Master of Science Thesis: 44 p
Supervisors: Prof. Jukka Rintala, Dr. Prasad Kaparaju, Mr. Hannu Hoviniemi
Inspectors: Prof. Jukka Rintala, Dr. Jussi Maunuksela
December 2009
Key words: anaerobic digestion, wastewater treatment, low temperature, Finland, China

Abstract

China has a long history and wide practice of applying small scale anaerobic digestion as a method to dispose domestic biowaste and provide energy for rural residents. There are also variety studies of utilizing anaerobic digestion process for small scale wastewater treatment. Despite the cold climate, small scale anaerobic digestion could also have a role to play in Finland for domestic wastewater treatment in dispersed settlements. The objective of this thesis was to provide an overview of small scale biogas plant applications in rural areas and the studies of onsite wastewater treatment in China, at the same time, explore the feasibility of designing a small scale onsite biogas wastewater treatment plant in rural Finland. Three different options were given based on the function of the plant and different substrates fed in. The COD removal of the anaerobic process could be expected at 80% at the temperature of 10-15℃ and nutrients could be recovered by using the sludge as a kind of fertilizer. Due to the low temperature and small amount of substrates, methane production would be limited.

CONTENT

Abbreviations

AD	anaerobic digestion
ABR	anaerobic baffled reactor
ABRF	anaerobic baffled reaction filter
BIOMA	Biogas Institute of Ministry of Agriculture (China)
BOD_5	5-day-biological oxygen demand
BOD_7	7-day-biological oxygen demand
COD	chemical oxygen demand
CODs	soluble chemical oxygen demand
CODt	total chemical oxygen demand
CSTR	continuously stirred tank reactor
GHG	greenhouse gas
HRT	hydraulic retention time
MOA	Ministry of Agriculture (China)
OLR	organic loading rate
SBR	sequencing batch reactor
TKN	total Kjeldahl nitrogen
TP	total phosphorus
TS	total solids
TSS	total suspended solids
UASB	up-flow anaerobic sludge blanket
USSB	up-flow staged sludge bed
VS	volatile solids
VSS	volatile suspended solids

1. Introduction

Anaerobic digestion (AD) process has been well practiced for wastewater and biowaste treatment as well as producing biogas in many parts of the world for its efficient organic removal and simple construction. Also, it produces much less sludge than aerobic process and requires little energy but produces biogas which is a form of clean and renewable energy. Meanwhile, the digestate sludge and effluent can be utilized as fertilizer in a way which the nutrients are recovered [1].

On the other hand, the performance of AD process compromises as the temperature drops, but the inoculum introduction and increasing knowledge have made it possible to operate reactors under low temperature (above 10℃). A simple post-treatment is also sufficient for the removal of pathogens and nutrients in the effluent which can not be fully removed in the AD process.

In China, producing biogas as an energy source for the rural residents is the main purpose of promoting small scale AD in rural areas. Through a long time period and large scale practices, China has built up a systematic institution for biogas development including research, technical support, facilities production and financial aid system. AD process plays a key part in the strategy of an environment friendly and sustainable rural society as it is widely used in small scale domestic wastewater and biowaste treatment plants.

In Finland, there is an opportunity for AD to play a role in the decentralized wastewater treatment plant. In 2004, an obligatory legislation for wastewater disposal came into force. It requires the minimal removal of 97% of biological oxygen demand (BOD_7), 85% of phosphorus and 40% of nitrogen from domestic wastewater. Despite the challenge of cold environment in Finland, several studies carried out in the laboratory have shown the possibility of applying AD at household scale under low temperature, but still a real practice is needed to examine the feasibility.

There are two main objectives for this thesis. The first object was to provide a general review on the Chinese experiences on AD utilization and development, introduce the institutions and technology research to provide a reference for its counterpart in Finland.

The second objective was to provide design options to build up a demosite in rural Finland using AD process for the wastewater and biowaste treatment. To achieve this goal, there were several minor objectives to be reached:

-review of related Finish legislations and current methods of rural domestic wastewater treatment;

-collection of basic information of the demosite such as climate, resident number, water consumption per person per day, hydraulic plan, *etc*;

-collection of wastewater samples from the demosite and determination of methane potentials of the samples;

-proposal of different design options and key operating data;

-evaluation of the options and post treatment.

2. Background

2.1. Biogas technology

The term biogas in this paper refers to a gaseous production from the AD process of organic matters under the work of anaerobic organisms. The composition and productivity of biogas varies due to different substrate and environment but the major components are still methane (CH_4) and carbon dioxide (CO_2) (see table 1). The typical composition of methane in biogas is 50-60% and the low calorific value of biogas is 22 MJ/m^3. Other components include hydrogen sulphide, ammonia, moisture, dust particles and organic silicon components, *etc*. [2].

Table 1 Methane yield and biogas production of typical substrates*

	Substrate character		Methane production		Biogas production	
	TS	VS	substrate	proportion in biogas	per VS	per substrate
	(%)	(% of VS)	(m³/t)	(%)	(m³/t)	(m³/t)
Cow manure	8.0	80.0	185	58.0	320	20.5
Pig manure	6.3	72.0	260	60.5	430	19.4
Barley (ripe)	27.4	93.2	589	64.0	920	234.9
Corn silage	35.0	96.0	366	58.1	630	211.7
Turnip rape silage	15.0	85.0	364	54.0	674	86.0
Bio wastes	52.5	60.0	400.0	57.1	700	220.5
Sugar beet chips (pressed)	22.0	90.0	380.0	45.2	840	166.3

*Source: RHB GmbH, http://www.rhb-berlin.de/en/stoffe.html, accessed in June 2009.

There are four basic phases of anaerobic processes: hydrolysis, acidogenic fermentation, acetogenic oxidation and methanogenesis. Three factors that affect the AD process are pH, moisture content and temperature.

Different phases have different optimum pH values. In multi-phase process, pH can be optimized according to the phase but in single reactor system, pH is normally at 7-8 according to the optimum of methanogenesis.

Water is compulsory for micro-organisms to survive and the reactions to take place after the hydrolysis of organic components. The optimum dry mater (total solid, TS) content is between 5-10% for wet AD process and 30% for dry AD process respectively [3].

There are four types of AD processes based on the temperature in general: psychrophilic (12-20°C), mesophilic (30-40°C), thermophilic (50-55°C) and extreme thermophilic (70-80°C) [3]. Temperature has a profound influence on the growth rate of the micro-organisms. The high doubling time of psychrophilic micro-organisms is 35 days comparing with it of 10 and 4 days of mesophilic and thermopilic micro-organisms [4] meanwhile, the activity of methanogens is 10-2 times slower at 15°C than activity at 35°C [5].

The utilizations of biogas are various. It can be used for cooking, lighting, heating and/or electricity generation. After desulfurization, it can be directly used as a fuel in gas boilers for heating or combined heat and power (CHP) plant. After gas purification, biogas could either be used in fuel cell to provide heat and power or injected into the gas grid. Purified biogas has a high composition of methane of over 90% and can be used as a transportation fuel for cars [2].

2.2. Small scale biogas utilization in China

In China, household small scale biogas reactor (normally less than 20 m^3) has an important role in rural sustainable development:

> First of all, it is an important energy supply for rural residents who have no or limited access to grid electricity or other forms of energy sources. Biogas can be directly used for cooking and lighting which consists most of the energy needs in the rural side of China;
>
> Secondly, it reduces the deforestation or greenhouse gas emissions from the combustion of fossil fuels;
>
> Thirdly, it helps forming a virtuous cycle of waste material flow and has significantly promoted the hygiene and health for rural residents [6].

In the developed world, household small scale biogas utilization also has environmental benefits in reducing GHG emissions and disposal of manure, sewage and life biowastes. If operated properly, it could be part of an independent energy system, which brings energy independence and economic benefits.

2.2.1. Biogas development in rural China

China’s biogas utilization started in the 1920s. Luo Guorui was a pioneer of exploiting the use of biogas in Shantou, south coastal Fujian province. In 1921, he built an 8 m^3 reactor in his house for demonstration and biogas was used for lighting at that time. In 1929, the first biogas company to spread this technology was formed by Luo in Shantou and later moved to Shanghai. Meanwhile, he also set up training organizations along the Yangtze River and in some southern provinces.

In 1958, Mao Zedong called for a development and dissemination of biogas in rural areas as part of the Great-leap movement. Little real progresses were made due to the political campaigns. In 1975, a conference of biogas development was held in Chengdu, the capital of southeast Si Chuan province. The Ministry of Agriculture (MOA), Chinese Academy of Science and The State Planning Commission (the predecessor of National Development and Reform Committee) were the cofounder of this conference. In 1977, an office for promoting biogas development was formed by the MOA; later in 1979, the Biogas Institute of Ministry of Agriculture (BIOMA) was founded.

During 1973-1978, c.a. 7 million biogas plants were installed as a Government plan. Most of them were abandoned later because of the flaws in the design, low quality of constructions and lack of service. This frustration resulted in a stagnation of biogas plant installation for almost 10 years (see figure 1).

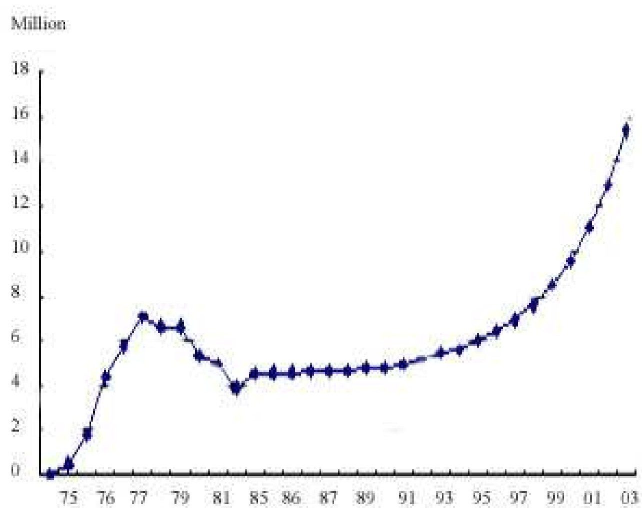


Figure 1 Household biogas plants growth in China (1973 – 2004) [7]

China’s biogas utilization finally started to grow in the mid 1990s. In 2002, the MOA finished the editing of the National Biogas Development Plan 2003-2010 and proposed that 50 million households should be able to use biogas in 2010. In 2007, MOA published a renewed version and reduced the number to 40 million.

From 2000-2006, the growth of energy consumption per capita in rural area was 69.1%, The average annual growth was 9.15%, which was 4.15% higher than the urban growth [8]. However, the absolute energy consumption in rural area was just 0.165 tce[1] per capita, which was 47.6% of the amount for urban areas [9].

In 2007, about three quarters of the energy supply in rural China came from straw and firewood (see figure 2). Most of the energy was used for cooking and house-heating.

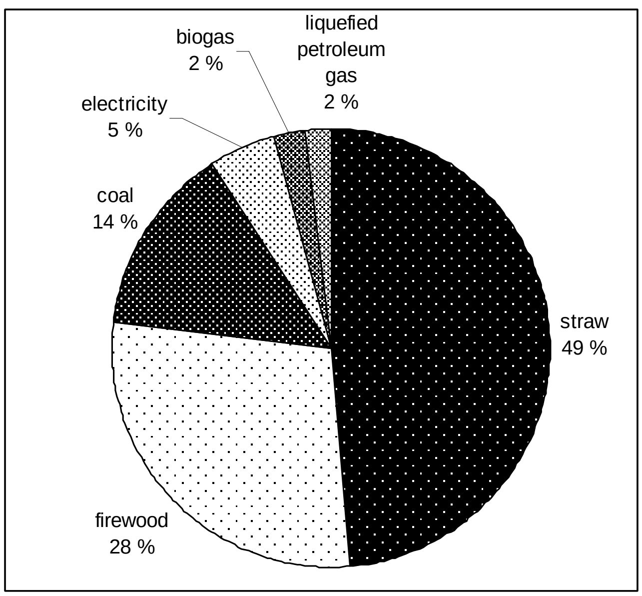


Figure 2 China’s rural energy composition, 2007 [9]

The growth of biogas plant installation has been accelerated since the beginning of the year 2000 (see figure 3). In 2007, China produced over 10 billion m^3 biogas from 26.5 million household plants and 26.6 thousand concentrated plants [7, 9]. Over 100 million

[1] tce = Tonne of coal equivalent, 1 tce = 29.3076 $\times 10^9$ J

people were benefited from biogas.

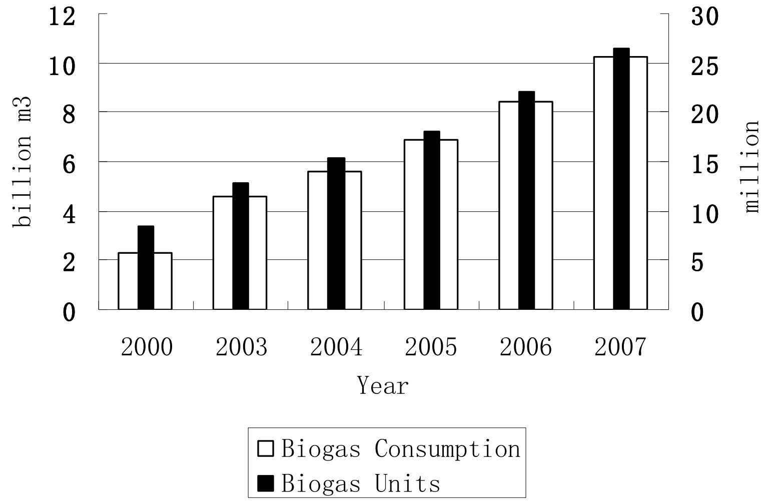


Figure 3 Biogas consumption (left) and number of domestic biogas plants in rural China (right) 2000-2007 [7, 9]

In March, 2007, the MOA published the National Rural Biogas Project Construction Plan 2006-2010. It declared that by the year of 2010, biogas would become the major energy source for c.a. 40 million rural households (160 million people) with an annual productivity of 15 billion m^3. These numbers could be doubled by 2020 (see table 2).

Table 2 Rural household biogas development plan in China, 2010-2020 [11]

Items	2010	2020
Rural households using biogas as primary energy supply	40 m	80 m
Beneficial population	160 m	300 m
Biogas consumption in rural household (m^3)	15 b	30 b

(m = million, b = billion)

To achieve this goal, 23 million new rural household biogas plants have to be constructed during 2006-2010. Among them, the central government will build 13 million, the local government will construct other 10 million [11] (see appendix i).

However, there are several constrains that limit the application of household biogas plant in rural areas:

The first one is the climate. In order to produce biogas continuously, the air temperature has to be above 10°C for most time of the year. Also there should be enough water supplies for the digestion. Among the total rural residents, 5% are living in unsatisfied areas.

The second factor is availability of biomass supply. Although manure is one of the most productive and common substrate for biogas production in China, 23% of the total rural households do not have enough pig manure, life biowastes and agriculture residue to feed a reactor.

The third factor is the economics. There are two opposite situations that biogas may not be a practical solution for rural residents: on the one hand, if there are abundant other energy sources available, such as grid electricity, coal, liquefied petroleum gas, wind and/or solar energy and the costs are affordable, then biogas may not seem attractive to them. On the other hand, if the costs of construction and accessories that have been excluded from the governmental financial aid are too high for rural households, then they will not be able to build the plants either. Because of these reasons, 17.5% of the total rural households fail to meet this criterion [6].

Despite these constraints, there are still 191 million rural households that could be the potential users of biogas [6].

According to the government plan, 4.33 billion euro[2] will be invested in rural household biogas construction during 2006-2010[3]. 30% of the total investment comes directly from the central government and 10 % from local government [6].

Table 3 shows the construction cost and subsidies from the central government and figure

[2] 1 Euro = 9.31 Yuan in July, 2009
[3] A 324 million euro extra investment was added in Dec, 2008 from government economic stimulation plan.

4 shows the geographic divisions. Local support policies may vary in different provinces.

Table 3 Financial balance of construction in different areas [6]

Area	Construction cost of rural household biogas plant (euro)	Central government subsidies per plant (euro)
Northeast	345.6	129.6
Northwest	345.6	129.6
Southwest	324	108
Middle	324	108
Others	324	86.4

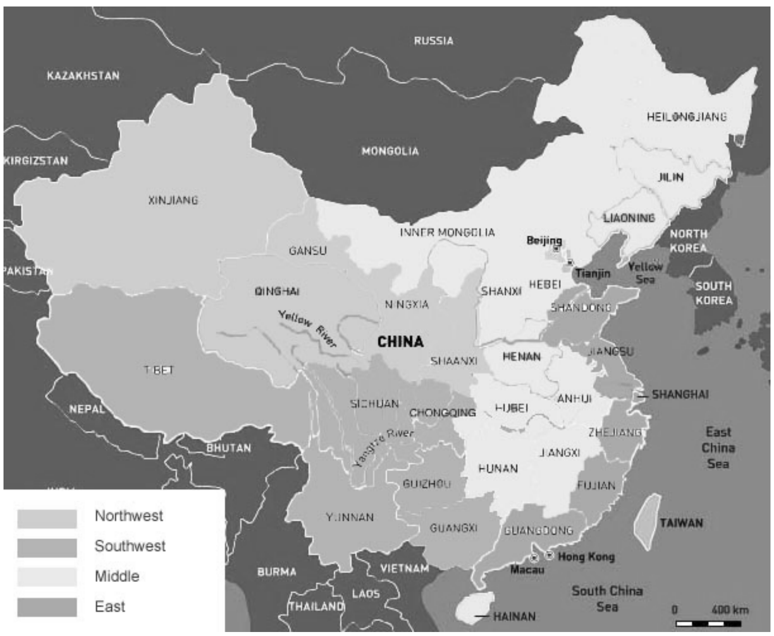


Figure 4 Geographic divisions for biogas development [6]

China’s Rural Household Biogas Project Development Plan targets at those who are still living in poverty or in a relatively poor economic situation. There are limited energy sources in their lives but biogas could be a practical and reliable option for them. Government financial aids and technical supports are crucial for the success of this plan. The MOA has built up a central supporting system and a group of organizations to promote the utilization biogas technology (see figure 5). At the same time, over 90% of China’s 2861 towns have set up Rural Energy Office as part of the rural administration agency to spread and support biogas construction. 50,000 managers and 150,000 qualified masons and technicians were trained to provide directions and service for local communities [9]. Service stations are built in towns and villages with the single capacity of serving 300-500 household biogas plants. Each station is equipped with an inoculum reactor, vehicles for feedstock and digestate transportation that are equipped with automatic feed-in and pump-out facilities, methane detector and acid-base meter, maintenance tools, exposure suits and a number of biogas utilization accessories. Private companies and individuals are encouraged to invest in building up service stations and networks. At the same time, there are now over 50 companies producing 5 million sets of biogas accessories each year.

A series of national standards were published to guide the construction of biogas plant and production of accessories. In 2001, The MOA published Household-scale Biogas & Integrated Farming System--Specification on Design, Construction and Use for Southern Model NY/T 465-2001 and Northern Model NY/T 466-2001. In 2002, the State Administration of Quality Supervision, Inspection and Quarantine renewed three national standards regarding to household biogas plant: The Collection of Designs for Household Anaerobic Digesters GB/T4750-2002; Operation Rules for Construction of Household Anaerobic Digesters GB/T4752-2002 and Standard for Check and Acceptance of the Quality for Household Aerobic Digesters GB/T4751-2002. Hydraulic reactor, floating cover reactor and other 3 models was presented as typical reactors in China. Meanwhile, a number of other national standards regarding to the utilization facilities and accessories such as the biogas stove, devulcanizer, pressure gauge and sealing paint were published. These standards have set up a guidance for the construction and operation of millions biogas plants.

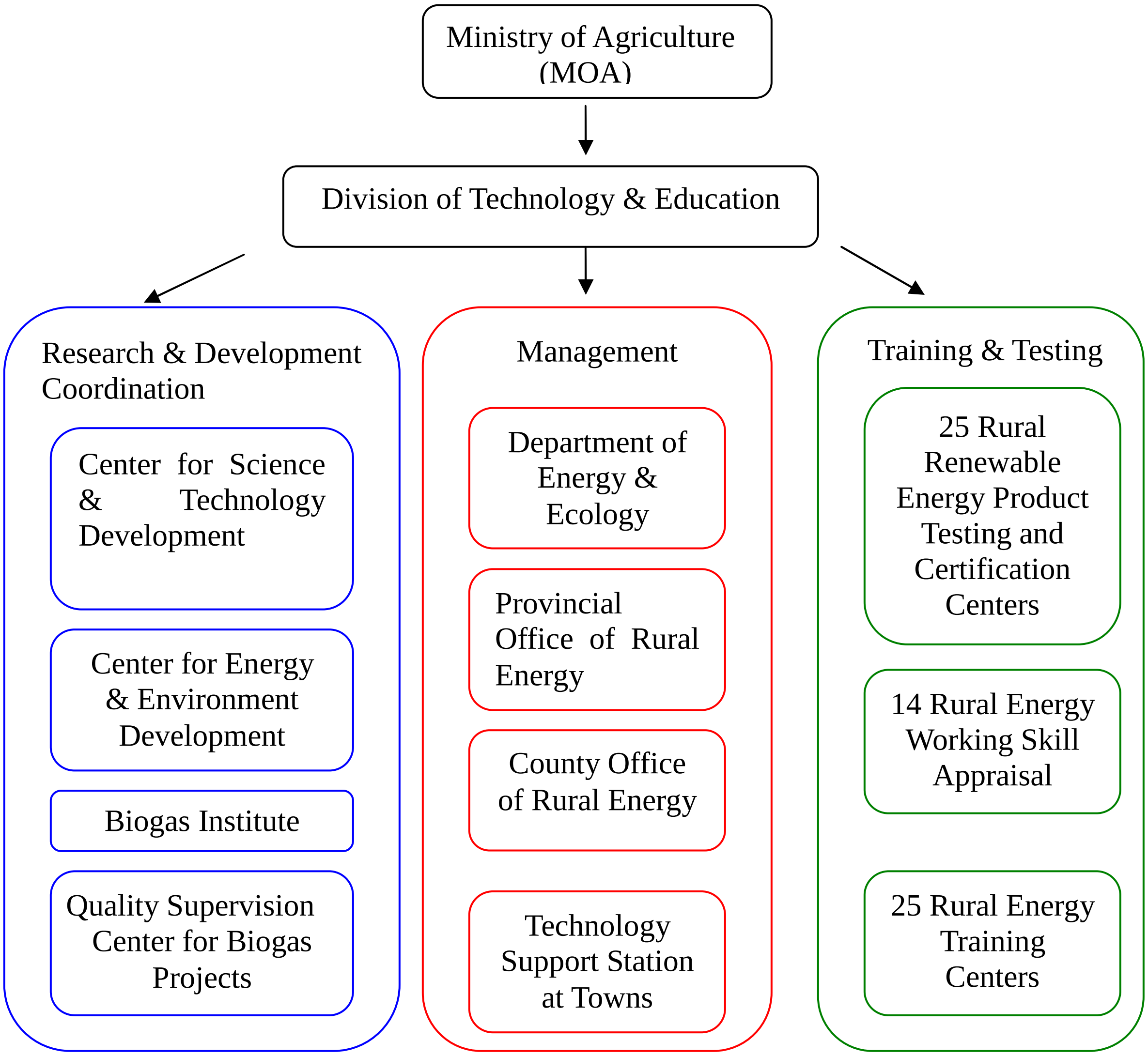


Figure 5 Supporting system for rural biogas development [12, 13]

2.2.2. Typical Chinese small biogas units and their applications

Based on the differences in climate and various biowastes in different areas, there are two typical biogas modules that are promoted by the MOA.

In southern China, the climate is generally warm and wet which creates a benign environment for AD. A typical rural household biogas plant in southern areas includes the construction of an 8 m^3 dome reactor and reconstructions of kitchen, toilet and sty. Such constructions and modifications provide a clean living condition, at the same time biowastes, sewage and manure were collected and delivered automatically to the reactor. The reactor in most cases is built under the sty to reduce the loss of heat and keep the temperature suitable for reaction (see figure 6 and 7). The digestate is pumped out and used as a kind of fertilizer for the garden.

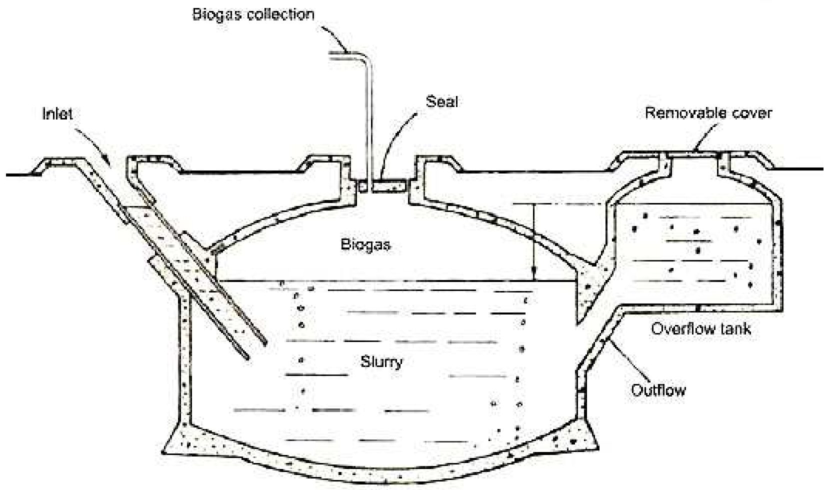


Figure 6 Typical hydraulic reactor in rural household use

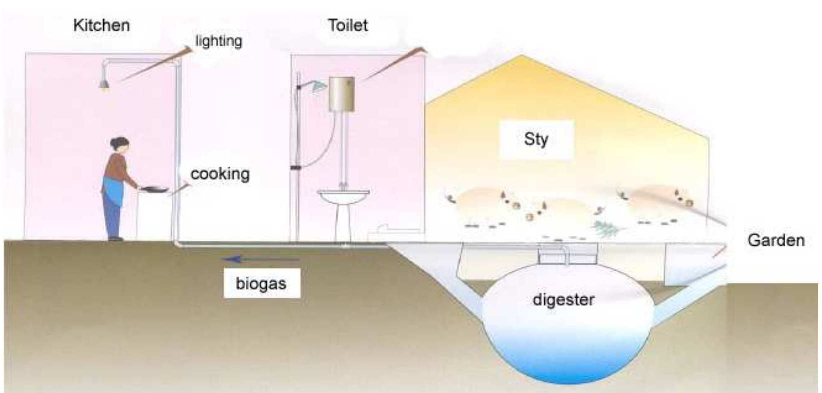


Figure 7 Typical biogas plant for rural household in southern China

In northern China, most areas have a temperature below zero during winter time. As a result, it is important to provide insulation and passive heating system to maintain the optimum temperature for AD. Solar heating belt is commonly used to raise the temperature of the sty and therefore the reactor under it. In the northeast areas where the temperature could easily fall below -10°C during winter, the toilet, sty and reactor are always built inside the greenhouse (also called 4 in 1 system, see figure 8) which are widely constructed in villages for vegetable farming. In the northwest provinces where most areas belong to the arid or semi-arid regions, cistern and irrigating system are connected to the reactor to provide enough water supply.

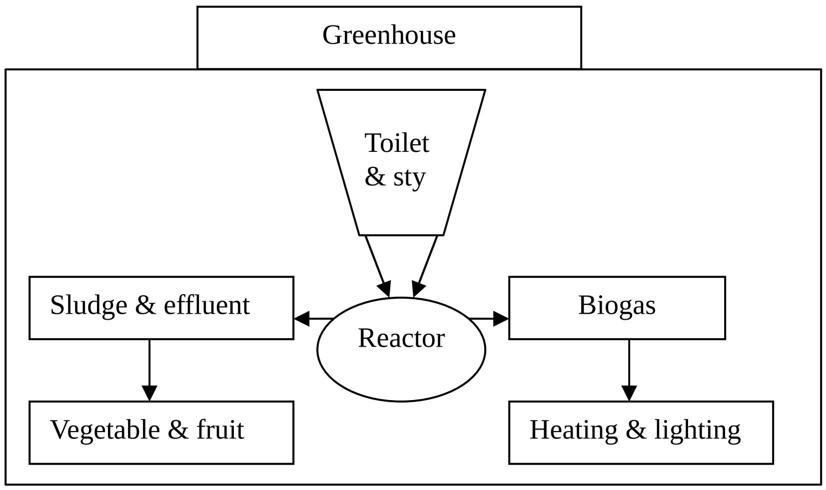


Figure 8 Typical biogas plant for rural household in northern China

The local condition and environment may vary very differently in real practice; therefore the construction of biogas plant is usually adjusted to fit the local situation.

2.3. Chinese studies on AD process for small scale wastewater treatment

2.3.1. General development

Since the 1980s, China started to build biogas wastewater treatment tank as part of the comfort station in cities based on the experiences from the construction of biogas septic tank and rural biogas dome. The southern Si Chuan province has published the General Engineering Drawing of Biogas Purification Tank for Domestic Wastewater Treatment in 1991 and a new version is due to publish by BIOMA in 2010. Later in 2003 and 2004, the southern Zhe Jiang and Jiang Su provinces also published their similar documents respectively. These publications gave an explanation of how to build biogas purification tank in small scale, but there are also many simplified and adjusted designs used in practice. By the end of 2004, there were 137,013 biogas domestic wastewater treatment facilities build in China with a total volume of 5.74 million m^3 [14].

2.3.2. Studies on AD process for wastewater treatment and post treatment

Studies on Anaerobic process

Xia Bangshou *et al* (2008) have collected five typical engineering drawings of biogas purification reactors and studied their designs. In general, they are based on a combination of unpowered anaerobic and aerobic process (see figure 9). The construction includes two-step anaerobic reactors and an aerobic reactor (see figure 10 and table 4). The required standards of the treatment results of the combined processes vary according to different designs. In Si Chuan Province, the COD of the effluent should be less than 200 mg/L [15] and in Jiang Su and Zhe Jiang provinces it should be less than 120 mg/L [16]. In practice, the composition of effluent may be very different due to the differences in influent, construction, operation and management [17].

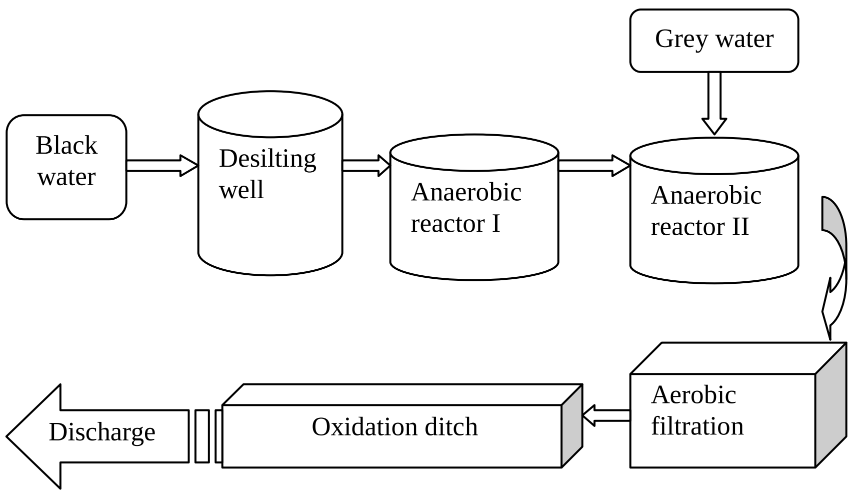
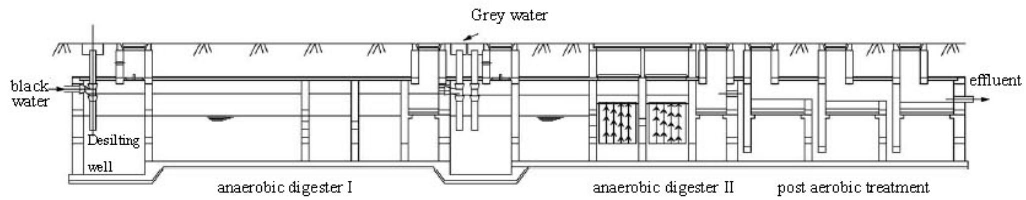


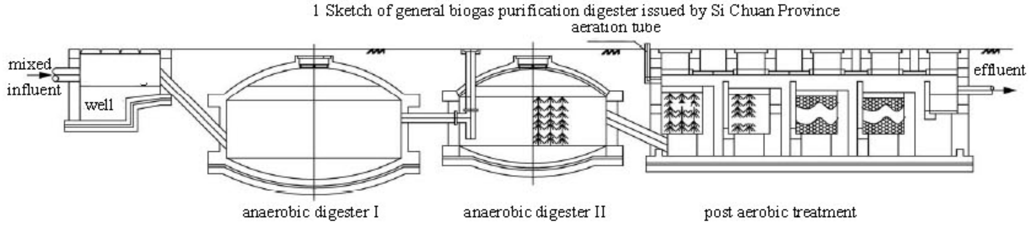
Figure 9 Typical process for domestic wastewater treatment in China

Table 4 Main parameters for five representative biogas reactors [17]

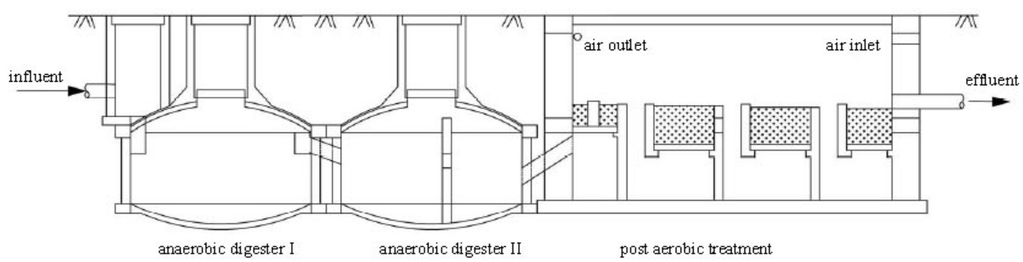
No. of design	HRT (h)	Combination of black & grey water	Effective Capacity (m^3)	Desilting well	Proportion of total volume			
					Sedimentation Place (%)	Anaerobic reactor I (%)	Anaerobic reactor II (%)	Post aerobic treatment (%)
1	72	Separated	100	No	10.2	33.5	31.7	24.6
2	72	Mixed	50	Yes	0	40.0	26.6	33.4
3	48-72	Mixed	17	Yes	0	35.0	35.0	30.0
4	96	Mixed	90	Yes	0	66.7	27.1	6.20
5	96	Mixed	60	No	12.5	18.8	56.2	12.5



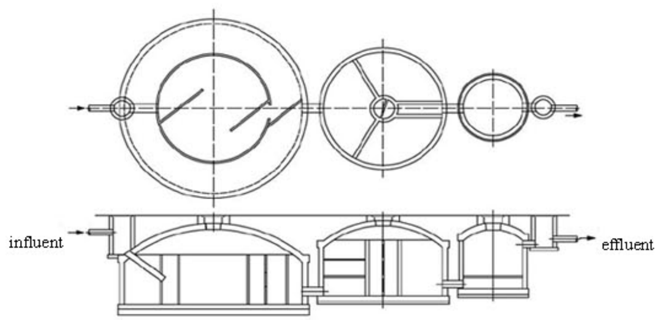
1 Sketch of general biogas purification digester issued by Si Chuan Province



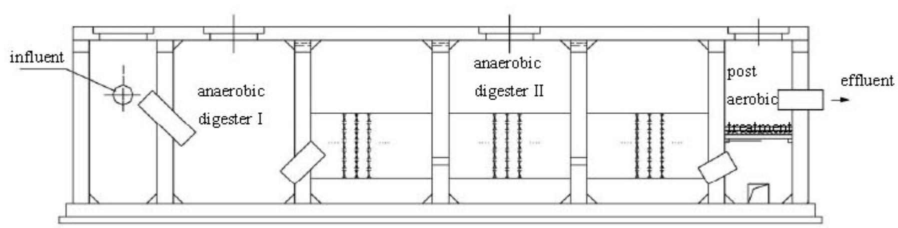
2 Sketch of general biogas purification digester issued by Zhejiang Province



3 Sketch of general biogas purification digester issued Jiangsu Province



4 Sketch of biogas purification digester used in Leshan primary school



5 Sketch of biogas purification digester used in Wenjiang community

Figure 10: Sketch of typical sewage purification biogas reactors [17]

Besides the application of typical biogas wastewater reactors, there have been studies on different reactors.

Hu Qichun *et al* (1996) in BIOMA studied the performance of a 11.6 L up-flow anaerobic sludge blanket (UASB) reactor with inclined tube settler (UASB/ITS) to treat the diluted distillery wastewater. After 77 days of commissioning, the reactor removed 78.9% of COD when the hydraulic loading was 2.0 $m^3/m^3/d$ and the influent COD was 767 mg/L, while the temperature was at 18℃. In the second period of the test (half a year later), the reactor recovered its full capacity just after one day of startup at 25℃. In the 129 days of test, average COD removal was 76.1% with influent COD between 660-982 mg/L and HRT was 12 hours (see figure 11). The UASB/ITS reactor could be operated at the temperature above 12℃ and these inclined plates have an obvious effect of retaining active sludge from the up-flowing water. The sludge was formed into large granulas on the plates, which provide of habitats for filamentous methanogens. Biogas production was between 0.57~0.66 m^3/kg COD for this process. In general, this technology was considered simple to build, fast to start, easy to control and stable in operation [18].

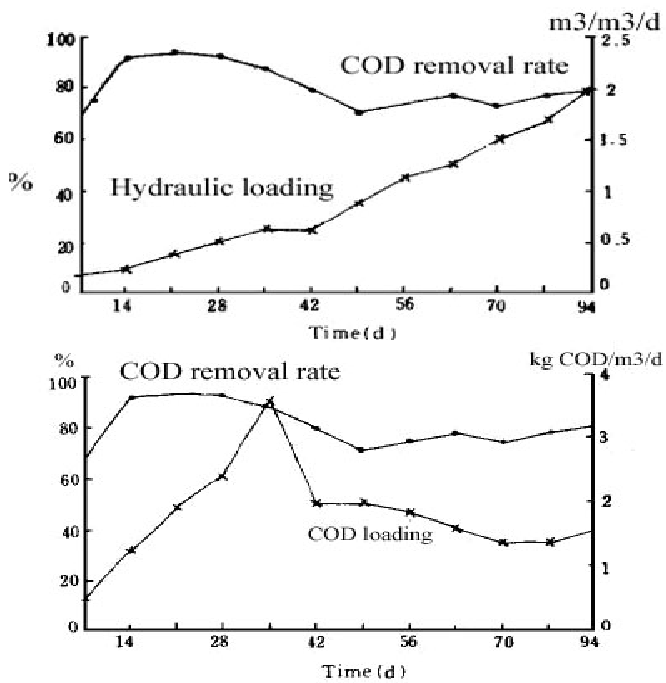


Figure 11 COD loading, hydraulic loading and COD removal of UASB/ITS test for diluted distillery wastewater at 18℃ [18]

Xiao Liping and Deng Zhiyi (2005) have studied the effect of using up-flow staged sludge bed (USSB) for domestic wastewater treatment. They separated a 7.6 L reactor made from polymethyl methacrylate into 6 connected sub-reactors. The temperature was controlled at 35℃±2℃ and the digested effluent flowed into an aerobic tank for further treatment. The result showed that the anaerobic removal efficiency of COD, NH_4^+-N and TP were 77%, 53.4% and 51.4% respectively. The concentration of COD in effluent was less than 100 mg/L, NH_4^+-N was less than 15 mg/L and TP was less than 1 mg/L (see table 5 and figure 12) [19].

Table 5 Domestic wastewater characters for USSB test [19]

COD (mg/L)	SS (mg/L)	pH	NH_4^+-N (mg/L)	TP (mg/L)
100~580	10.1~68.9	6.8~9.4	13.4~33.6	1.9~11.8

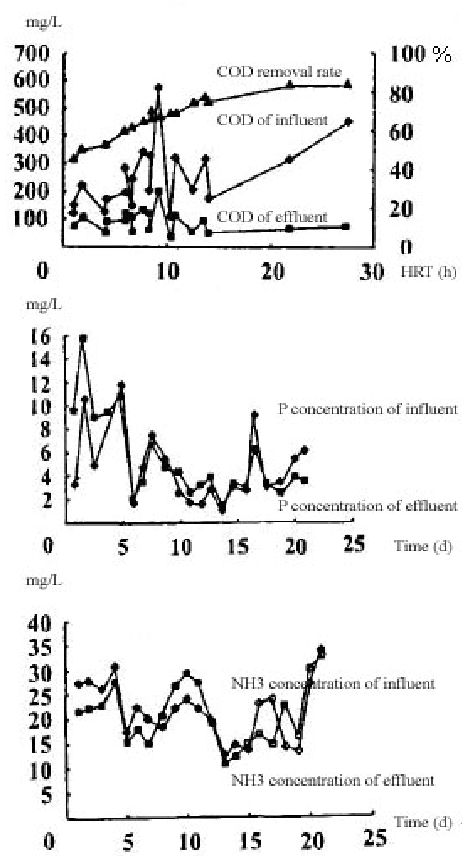


Figure 12 COD, P and NH3 removal of the anaerobic reactor in the USSB test [20]

Chen Junjie (2008) did an experimental research on anaerobic baffled reactor (ABR) treatment of rural domestic wastewater. It was shown that ABR has a good adaptability to the changes of HRT and COD loading, and the COD removal stayed between 65-75% when the temperature was between 25-32℃. As the temperature was decreased from 30 ℃ to 10℃, the COD removal dropped from 75.2 to 67.2% [20].

Fu Jiayuan and Dong Fakai (2003) tested the performance of anaerobic baffled reaction filter (ABRF) for domestic sewage treatment at ambient temperature (c.a. 25℃). The results showed that there was a negative linear correlation between OLRs and COD removal (see table 6) [21].

Table 6 Performance of ABRF for different domestic wastewater treatment [21]

Flow		(m^3/d)	28	33	41	55	82
HRT		(h)	17	14.5	11.7	8.7	5.8
OLR		(kg COD/m^3/d)	0.37	0.41	0.53	0.62	0.8
COD	influent	(mg/L)	250	235	246	213	187
	effluent	(mg/L)	68	76	87	88	84
	removal	(%)	73	68	65	59	55

Studies on combined anaerobic and aerobic process

Li Xiaohui *et al* (2006) have done feasibility study of removing organics and nitrogen from sewage water in the UASB/Bio-filter (BF) system. The temperature of the system was controlled between 27-30℃. The HRTs employed were 12, 10, 8, and 5 h. The OLRs were 1.0, 1.2, 1.5, and 2.0 g COD/L/d and the total nitrogen loading were 62.5, 75.3, 82.8, and 159.3 mg/L/d. More than 92% of influent COD was removed at all loadings tested. The removal of total nitrogen was about 83, 80, 76 and 68 % respectively [22].

Wang Congliang *et al* (2001) studied the treatment of domestic sewage by hydrolytic-aerobic system. Given the retention time of 16 h and average influent temperature at 23℃, 80% of COD, 90% of BOD_5, 85% of SS and 87% of NH_4^+-N were removed [23].

Wang Cuilan *et al* (2005) developed a process using ABR acidification and two-stage constructed wetlands for domestic sewage treatment. The results showed that the average removal and effluent leftover of COD, BOD_5, TKN and TP were 92% (≤100mg/L) , 98% (≤30mg/L) , 29% (≤15mg/L) and 64% (≤0.5mg/L) respectively [24].

Peng Zongyin (1999) has developed a small household wastewater treatment system with UASB and aeration system integrated in a stainless steel tube. At the temperature of 20℃ and HRT of 7 h, the removal of BOD_5 and NH_4^+-N could reach to 90% and 78.3% respectively [25].

Qi Yao *et al* (2008) have investigated 62 decentralized wastewater treatment plant (reactor volume <1*10^4 m^3/d) built from 1996 to 2008 and get the distribution of usage of technologies (see figure 14) [26].

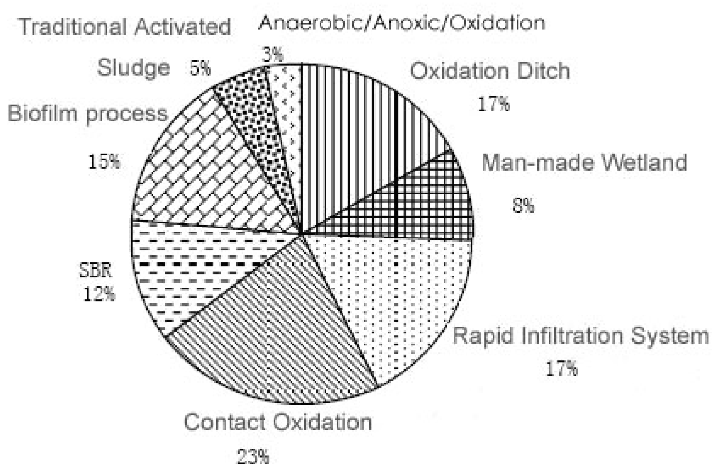


Figure 14 Usage of technologies for decentralized sewage processing in China [26]

Digestate disposal and utilization

Guo Qiang *et al* (2005) gave a comprehensive review of different utilizations of digested effluent using substrate from food industry. It was found that the effluent has obvious and positive effects in various agriculture sectors, including animal feeding, fish farming, mushroom farming, seed soaking, *etc*. Using pathogen removed effluent as additive of feedstock for pig farming has reduced the breeding period for 1-2 month and increased the weight of 8.2 kg per pig. Using pathogen removed effluent instead of water to mix the feedstock for chicken farming has increased the egg production by 7.8 % and reduced the broken rate. Using effluent and digestate with other fertilizers for maize farming has increased the production from 12-21%. Wheat seeds soaked with effluent has increased the sprout of 100.000/ha and raised the production of 750 kg/ha [27].

Zhang Quanguo (2005) also has generated various studies and experiments on the utilization of AD digestate (sludge) including combined fertilization to improve soil quality, feedstuff for animal breeding (pigs, fish, fishworm, *etc*.), substrate for mushroom farming and so on. Using digestate to substitute 15% of the feedstock in pig farming has sharply reduced the disease of digestive tract and increased the meat content by 1.25% [28]. Table 7 shows the change of soil character after two years fertilization by AD digestate with different loading per hectare for each sample. The raise of organic matters and nitrogen content in the soil showed a positive effect.

Table 7 Change of soil character after two years fertilize by AD digestate of different loadings [28]

Loading of digestate	Organic matters in soil		Nitrogen content in soil	
	before	after	before	after
(t/ha)	(%)	(%)	(%)	(%)
15	1,61	1,92	0,084	0,092
45	1,57	2,06	0,076	0,113
90	1,91	2,43	0,092	0,123

2.4. Finnish legislation and technologies regarding to domestic wastewater treatment

Finland has a low population density of 16 p/km^2; however, 62% of the total 5.2 million population live on 4% of the urban territory [29], in another word, 48% of the population, *i.e.* about 2.5 million people, live in small towns and dispersed settlements.

About 20% of the population lives in 350,000 permanent houses that are not connected to centralized sewage systems, besides there are also 450,000 summer houses in rural areas which are used mainly during May to September [30].

In 1961, Finland has published The Water Act which initiated a comprehensive process of wastewater treatment plant construction in towns and even in villages. By 1985 every town and village with more than 200 inhabitants had a treatment plant [31].

From 1976, every 10 years, the government published National Water Protection Targets. The reduction of water pollutant discharged from large industrial sources and municipalities were succeeded and then the wastewater disposal effect from dispersed settlements without sewage network became obvious. In 1998, the government set a goal for at least reducing BOD_7 by 60%, phosphorus by 30% compared with the 1990s national level. In order to meet this goal, a more comprehensive and restricted regulation was needed.

A new Environmental Protection Act came into force in 2000. It allows the government to issue more strict regulation of onsite wastewater treatment. Later that year, the Ministry of Environment started the preparation of the decree. Experts from legislation, environment and engineering came together with the representatives of main stake holder groups to form the proposal. After revisions and political debate, in 2003, based on the proposal, the Finnish government issued Government Decree on Treating Domestic Wastewater in Areas Outside Sewerage Networks (OWSD) and it came into force on Jan.1.2004. The Decree sets minimum standards for wastewater treatment and the planning, construction, use and maintenance of treatment systems. The requirements in the Decree apply immediately to all new buildings, while wastewater treatment systems of buildings completed before Jan.1.2004 must in most cases are upgraded to fulfill the new standards by 1.1.2014. Nearly one fifth of the population living in dispersed settlements were affected and hundreds of thousands of summer houses have to be equipped with proper wastewater treatment facilities.

The decree gives an important definition of person-equivalent load for dispersed settlements (see table 8) as a reference for the consideration of design of wastewater treatment if primary data is difficult to get. Based on this person-equivalent load, the decree sets the reduction requirements for domestic wastewater treatment which is 90% removal of BOD_7, 85% removal of phosphorus and 40% removal of nitrogen. Therefore, the maximum leftover could be calculated in table 9. In some less sensitive places the reduction could be lower as a reduction of 80% BOD_7, 70% total phosphors and 30% of total nitrogen.

Table 8 Composition of the person-equivalent load for dispersed settlements; origin of loading and the amounts of different types of loading as grams/person/day (g/p/d) and their percentages (%) [31]

Origin of loading	BOD_7		Total phosphorus		Total nitrogen	
	(g/p/d)	(%)	(g/p/d)	(%)	(g/p/d)	(%)
Feces	15	30	0.6	30	1.5	10
Urine	5	10	1.2	50	11.5	80
Other	30	60	0.4	20	1.0	10
Person equivalent load	50	100	2.2	100	14	100

Table 9 Required reductions of components in Finnish domestic wastewater [31]

Load parameter	Load of untreated water (g/p/d)	Leftover (g/p/d)	Required reduction (%)
BOD_7	50	5	90
TP	2.2	0.33	85
TKN	14	8.4	40

The emphasis of this decree is on the effect of pollutant removal, not on the choosing of specific technology or the concentration of treated effluent. However, it is clear that by using certain technology procedures such as dry toilet, the loading of wastewater components would be much less and it is also easier to reach the requirement according to the person-equivalent load.

The equal requirement set by the decree encourages the developing of different kinds of technology process and equipment. However, effective and economic prefabricated systems are still needed to take over the role of septic tank and soil absorption system. The following table shows the current options for dispersed settlements.

Table 10 Common optional technology for wastewater from summer house by the Finnish Environment Institute*

Standard of equipment	Appropriate treatment method	Remarks
Dry toilet + Water carried in and out (buckets and washbasins)	Such small amounts of wastewater can be discharged directly onto the ground, e.g. to a flower bed	- Be sure that the washings don't run directly down to a water body - Don't discharged washings on the ground near to a well - Use environment-friendly detergents - Food scraps belong to the compost bin. If you don't have a composter, use the waste container.
Dry toilet + Water carried or pumped in manually + Washings conducted out through a sewer (kitchen sink, washbowl)	Permeable ground (e.g. gravel, sand): Small settling tank (200-300 liters) + simple soil infiltration system (e.g. pipes with holes or infiltration through the bottom of a specially made tank)	-- Self-made treatment systems are possible but there are also factory-made systems appropriate for use at a summer house. - Empty the tank once every summer. Don't bury the sludge into the ground, compost it.
	Aquifer areas or non-permeable ground (e.g. bedrock); Factory-made device, e.g. a grey water filter planned for use at a summer house	Grey water filters can be obtained from consults and vendors and from municipal environmental authorities.
Dry toilet + Tap water	Permeable ground (e.g. gravel, sand): Primary settling in a double settling tank + soil infiltration or Primary settling in a double settling tank + sand filtration	- Subsurface wastewater disposal systems (infiltration or filtration plants) require a sufficient ground area (20-30 m^2), sufficiently far away from wells and shores.

	Groundwater aquifer area or non-permeable ground (e.g. bedrock); Treatment without infiltration into the soil (e.g. sequencing batch reactor plant or biofilter) or Primary settling in a double settling tank + sand filtration (NOT soil infiltration)	- In order to function as they should, treatment plants require regular maintenance and service. In several plants, the treatment chemical must be added regularly. - Long absence from the summer house may weaken the treatment efficiency. Several treatment plants work normally in regular use only. - If the summer house is far away from population center, the service costs may be high due to long distances.
Water closet + Tap water	The wastewater treatment system should be selected together with an expert. The choice may be restricted by the regulations of town plans and municipal environmental authorities	- If the summer house is far away from population center, the service costs may be high due to long distances. - The road to the summer house must be accessible for heavy transport equipment.

* http://www.environment.fi/default.asp?contentid=277249&lan=EN&clan=en#a0, accessed in July 2009.

3. Materials and methods

3.1. Description of the site

The proposed onsite AD plant for domestic wastewater and biowaste treatment is at Mr. H' s farm which locates near Kouvola (N 67.3, E 34.8) in southern Finland. The mean annual temperature of southern Finland where the site locates is about 5.5 °C. From June to August, the average temperature is 15 °C and from December to February, the average temperature is -4 °C; the lowest temperature is from -35 °C to -45 °C and the highest is from 32 °C to 35 °C [36]. The diurnal temperature difference is about 8 °C [32]. Table 11 shows the monthly average earth skin temperature and the temperature under the periodically frozen layer (more than 100 cm in depth) would be somewhere between 0 °C and 6 °C throughout the year.

Table 11 Monthly average earth skin temperature (°C) of Kouvola*

Jan	-5.46	Apr	1.88	Jul	15.93	Oct	6.60
Feb	-7.16	May	7.43	Aug	15.42	Nov	1.61
Mar	-3.91	Jun	12.45	Sep	11.47	Dec	-2.73

*Atmospheric Data Center, NASA.

The demosite is also considered to treat wastewater from nearby neighbors Mr. J and Mr. S's houses. Normally, there are 3 persons live at Mr. H's place, 2 persons live at Mr. J's place and 3 persons live at Mr. S's place. Mr. H also has been breeding 6 horses on his farm (see figure 16).

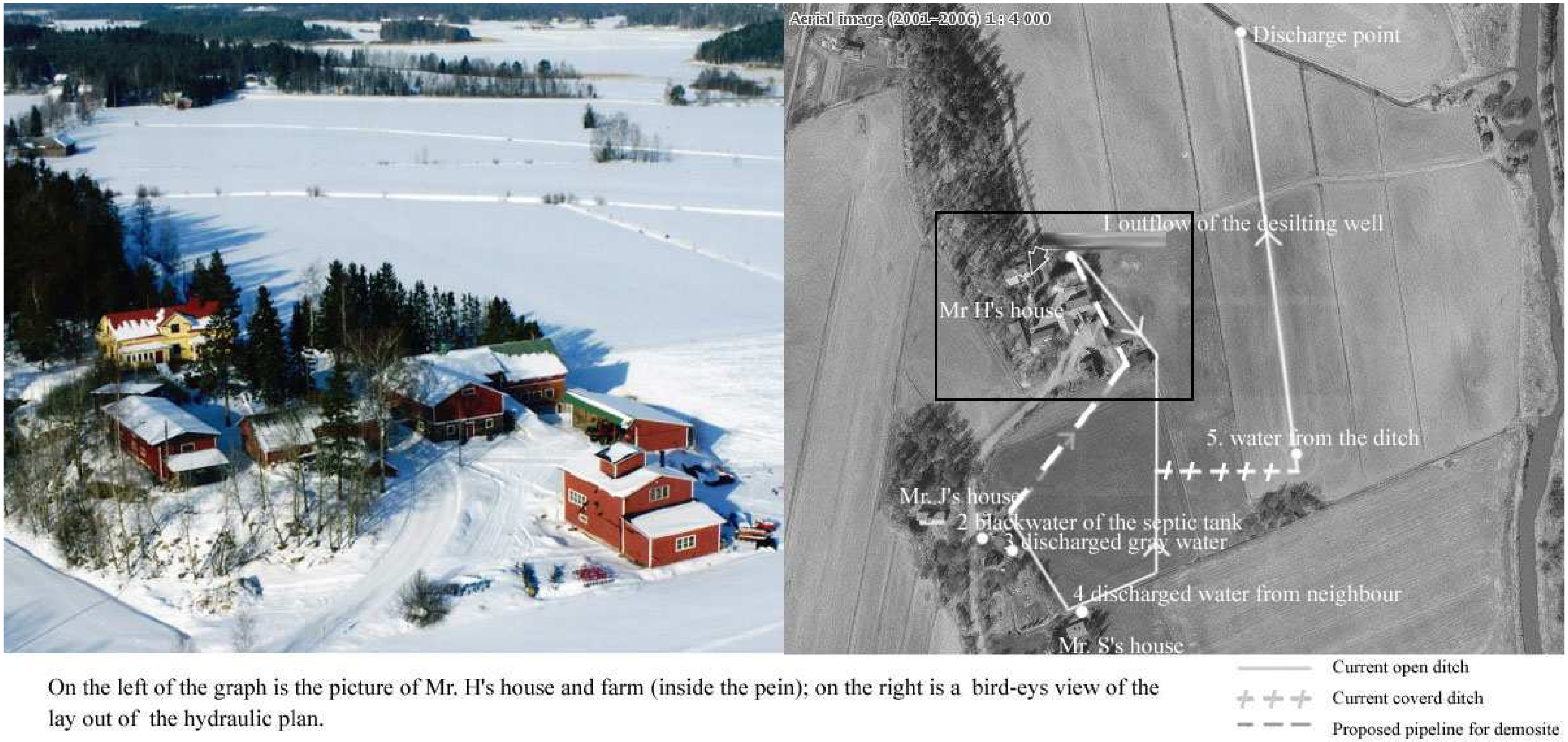


Figure 16 Airscape and hydraulic plan of the demosite

3.2. Data collection and sampling methods

Considering the practical conditions and availability, five representative samples of wastewater were taken from the demosite (see figure 17). The current wastewater treatment system at Mr. H's farm is an over 900 meters long open oxidation ditch. The ditch connects the mixed grey and black water from Mr. H's distilling well (sample 1) and grey water from Mr. J's house (sample 3). Black water in J's place (sample 2) was saved in a septic tank and periodically transported to municipal wastewater treatment plant. Because of the penetration and vaporization, there was no water flowing in the last 200 m of the oxidation ditch; therefore, the water sample 5 which represented the characters of discharging water was taken from point 5. The black and grey water were also mixed in the Mr. S's house and it was taken as a reference (sample 4); horse manure (sample 6) from Mr. H's place was also taken to analyse the potential influence of biogas production. Together, there were 6 samples taken once at the same time.

Two duplicates of each sample were collected directly from the desilting wells and ditch into two 1 liter volume PVC buckets. These buckets were sealed and stored into two ice boxes for transportation.

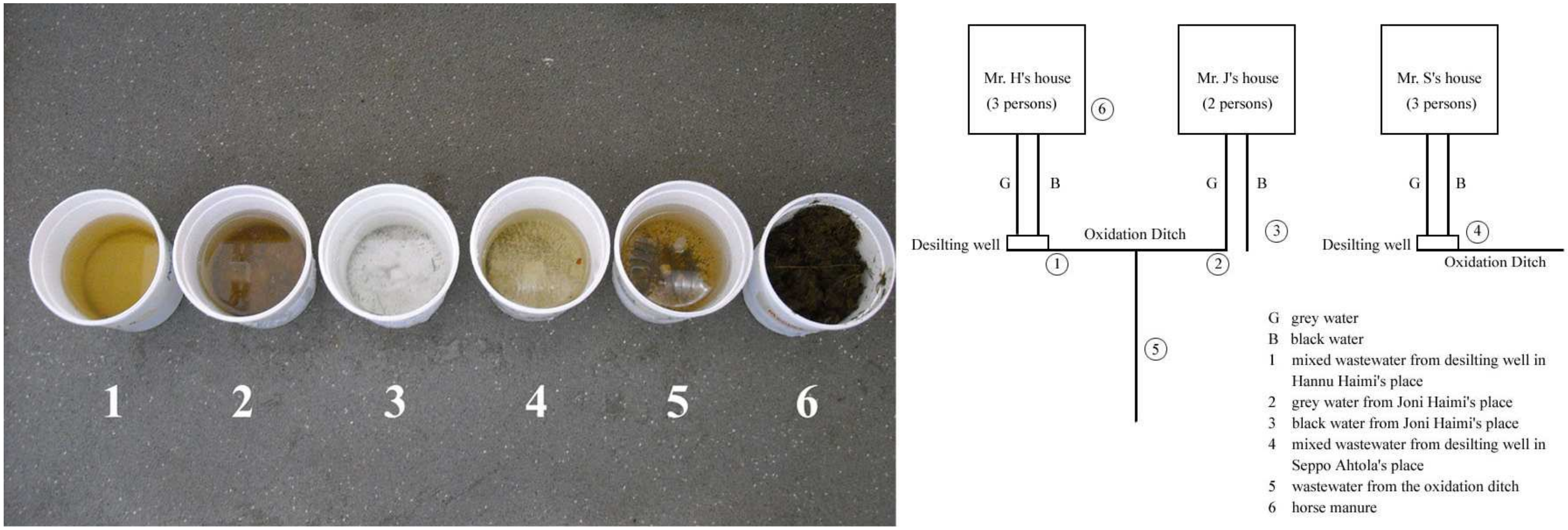


Figure 17 Samples taken from the demosite

3.3. Analysis

3.3.1. Wastewater and manure

The two duplications of these 6 samples were sent to the biogas laboratory of Department of biological and environmental science and Environmental research center of University of Jyvaskyla (YMTK, Jyväskylän Yliopisto Ympäristöntutkimuskeskus) respectively.

Immediately after the samples were taken on the site, the temperature was measured by a thermal meter and pH values were tested by Whatman pH 1-14 Reel Traditional Test Paper. TS, VS, TSS, VSS tests were operated following the standard methods [33]. Soluble COD (COD_s) and total COD (COD_t) of wastewater were measured according to the SFS 5504 standard [34]. Wastewater and manure samples for COD_s and NH_4^+-N were filtered using GF 50 glass fibre filter papers (Schleicher & Schhuell) before analyses. NH_4^+-N and total nitrogen (TKN) were analysed by Tecator Application Note [35] with Kjeltec system 1002 distilling unit. The BOD_7 and phosphorus were tested in YMTK based on the methods of SFS-EN 1899-1:1998 and A40B (Aquakem) respectively. Methane volume was analyzed with a Perkin Elmer Autosystem XL gas chromatography through a flame-ionization detector.

The removal of certain indicator (COD_t, TKN and P) was calculated by the number after treatment subtracted the number before treatment and then multiplied by 100%.

3.3.2. Batch experiment

Methane potential of wastewater, manure and the mixtures of them were assayed in duplicated 120 ml glass bottles which have a liquid capacity of 112 ml. For each bottle, 70 ml of wastewater as substrate was added in (for manure test, it was 69 ml distilled water and 1 g of manure and for the mixture test it was 69 ml of all equal volume mixed wastewater samples and 1 g of manure). Also, 20 ml of inoculum which was collected from the Nenäinniemi wastewater treatment plant was added into the bottle together with each sample. Meanwhile, three bottles with 20 ml of inoculum and 70 ml of distilled water without substrate were prepared for the test as a control. After sealed with butyl rubber stoppers, the content of these bottles was then flushed by nitrogen (98.8%) with needles snapped through the stoppers for 3 minutes. These samples were incubated in 35℃ constant temperature room for fermentation. Before sampling the methane production, these bottles were gently manually shaken and then 0.1 ml biogas was taken by a pressure locked syringe to the flame ionization detector of the gas chromatography for analysis. The methane test was taken 3 times a week in the first 2 weeks and with less frequency later.

3.3.3. Design methods

The design of the reactor type and key factors of the demosite are based on the investigation and experiment results and relevant literature. The reactor type will be chosen considering the reliability and performance in former studies. Main considerations include substrate's property (water consumption, feedstock, COD and VS), operation data (temperature, OLR and HRT), performance expectation (methane production, COD_t removal), post treatment (digestate property and sludge disposal) and nutrient recovery methods.

4. Results

4.1. Wastewater and biowaste loads and characteristics

4.1.1. Loads

The water consumption in Mr. H' s house (3 persons) is 635 L/ d and black water production is 210 L/ d (see table 12). Based on the average water consumption per person, then the annual total production of wastes of all these 3 houses was calculated. The annual black water production is 408.8 m^3 and grey water production is 204.4 m^3 (see table 13). Meanwhile, there are also 14 kg horse manure and 1.6 kg kitchen waste produced every day.

Table 12 Total waste production of Mr. H's house*

Source	Effluent temperature (℃)	Volume (L/time)	Frequency (times/day)	Subtotal (L)
Kitchen	15	10	5	50
Dishwasher	40	20	1	20
Toilet	10	8	6	48*3person
Shower	30	80	1	80*3person
Hand washing	20	5	5	25*3person
Clothes washing	30	40	1	40

* Based on investigation and estimation by the residents.

Table 13 Waste production of the demosite (8 persons)

Daily production of black water	(L/d)	384
Yearly production of black water	(m^3/a)	140.2
Daily production of grey water	(L/d)	1200
Yearly production of grey water	(m^3/a)	408.8
Daily production of kitchen waste	(kg/d)	1.6
Yearly production of biowaste	(kg/a)	584
Daily production of manure per horse*	(kg/a)	14
Horse number		6
Daily production of manure	(kg/d)	84
Yearly production of manure	(kg/a)	30,660

*Only manure without soiled bedding and urine.

4.1.2. Characteristics

In general, all the tested parameters were higher for black water and lower for the treated water from the ditch. The COD_s levels of all these wastewater samples were below 200 mg/L. There were slight differences between the mixed wastewater from Mr. H and Mr. S's place, but obvious differences between black water and grey water from Mr. J' s place.

The bedding for the horse stable was straw and the horse manure was collected by human labor. Due to practical reasons, biowaste from the kitchen were not taken for test and its production and characters were estimated from literature. The analyse results are shown in tables 14, 19 and figures 18, 19.

Table 14 Characteristics of wastewater samples

Factor \ Sample		Mixed black& grey Water in H's house	Black water in J's house	Grey water in J's house	Mixed black & grey water in S's house	Water from the ditch	Manure
pH		7	8	7	8	6	n.d.
Temperature*	(℃)	15	14	15	15	15	n.d.
NH_4^+-N	(mg/L)	34.3	315.7	14.9	81.8	3.2	6.8
TKN	(mg/L)	140	500	30	140	30	330
COD_s	(mg/L)	170	180	140	130	120	n.d.**
COD_t	(mg/L)	220	360	180	170	130	n.d.
BOD_7	(mg/L)	180	140	110	140	12	n.d.
TS	(%)	0.02	0.09	0.06	0.07	0.08	24.2
VS	(%)	0.01	0.05	0.06	0.05	0.05	20.8
TSS	(%)	0.01	0.02	0.01	0.01	0.04	n.d.
VSS	(%)	0.01	0.02	0.01	0.01	0.01	n.d.
P	(mg/L)	7.4	41	4	12	3.2	n.d.

*Ambient temperature was at 16℃.

** n.d. = not detected.

Table 15 Methane potential of selected samples

Sample	Cumulative methane yield (mL)		Methane yields (mL/ g COD_t)	
Mixed waste water from desilting well	7.79	(1.87)	375.8	(113.2)
Black water	8.34	(8.34)	251.7	(52.6)
Grey water	5.14	(5.14)	320.4	(27)
Mixed black+grey water	6.11	(6.11)	345.2	(72.6)
Mixed waste water from oxidation ditch	1.88	(0.37)	0	
Manure	51.14	(4.26)	n.d.	
Mixed wastewater + manure	71	(0.85)	n.d.	

- Samples are triplicate. Standard deviations are in parenthesis.

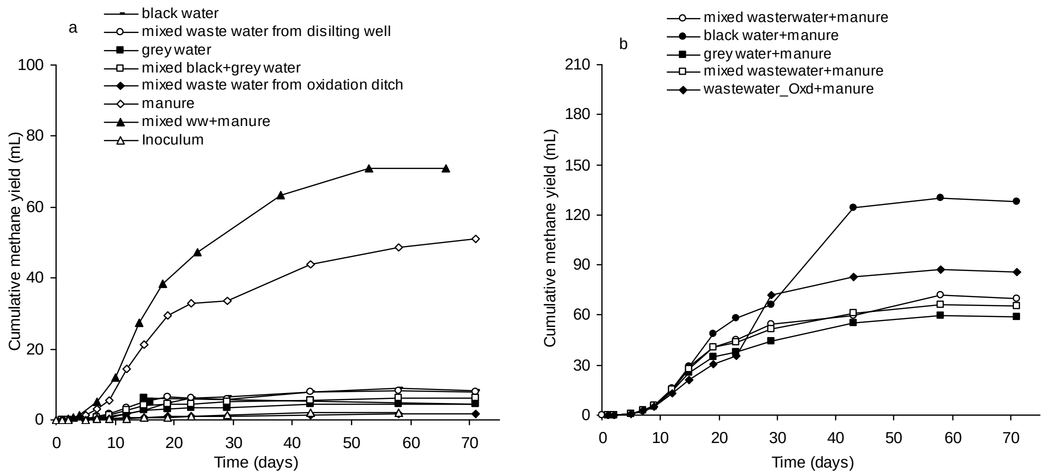


Figure 18 Cumulative methane productions of selected sample (a is the cumulative methane yield of different wastewater and manure samples; b is the cumulative methane yield of mixtures of wastewater samples and manure)

4.2. AD and post treatment

Based on literature and educated guess, there are three suggested options considering the different feedstock to the reactor (s). Table 20 shows the details of the all the three options in feedstock, reactor design, operating data, AD performance and post treatment.

Table 20 Options for onsite AD plant based on different feedstock

		Option I	Option II	Option III
Feedstock		wastewater	wastewater + biowaste	wastewater +biowaste +manure
Influent volume				
Black water	(kg/d)	384	384	384
Grey water	(kg/d)	1120	1120	1120
CODt				
CODt of black water	(g/d)	138	138	138
CODt of grey water	(g/d)	224	224	224
Solid waste				
Kitchen waste	(kg/d)	N/A	1.6	1.6
Manure	(kg/d)	N/A	N/A	8.7
VS				
Black water	(kg/d)	0.2	0.2	0.2
Grey water	(kg/d)	0.56	0.56	0.56
Kitchen waste	(kg/d)	N/A	0.43	0.43
Manure	(kg/d)	N/A	N/A	1.81
Total VS	(kg/d)	0.76	1.19	3
Reactor design				
Reactor type		single-phased UASB	two-phased UASB	CSTR
Working volume	(m^3)	7.5	7.5*2	45
Reactor volume	(m^3)	10	10*2	56
Operating data				
OLR		0.23 kg (COD_t /m^3/d)	0.76 kg (VS/m^3/d)	2 kg (VS/m^3/d)
Operating temperature	(℃)	10 (Winter) 15 (Summer)	10(Winter) 15(Summer)	10(Winter) 15(Summer)
HRT	(d)	5	5	30
Performance of AD process				
COD_t removal	(%)	80	80	80
TKN removal	(%)	40	30	30
Phosphorus removal	(%)	80	70	70
Methane yield 15℃	(m^3/d)	0.09	0.46	0.9
10℃		0.03	0.15	0.3
Methane yield per reactor volume 15℃	(m^3/ m^3)	0.009	0.05	0.02
10℃		0.003	0.02	0.007
Energy production 15℃	(MJ/d)	3	16	30
10℃		1	5	10
Post treatment				
Effluent treatment		open oxidation ditch	open oxidation ditch	open oxidation ditch
Sludge				
Sludge treatment		fertilization	fertilization	fertilization
Desludging period		once a year	every 6 month	every 6 month

4.2.1. Option 1: Single-phased UASB reactor for wastewater treatment

A single-phased UASB reactor is proposed for this demosite. The daily wastewater production is 384 kg/d of black water and 1120 kg/d of grey water which provide 0.07 kg and 0.17 kg COD_s /d respectively. Given the 5 d HRT time, the working volume of the reactor needs to be c.a. 7.5 m^3 which takes 80% of the 10 m^3 whole reactor volume. The outflow of the wastewater from the houses is about 15℃ during summer and 8℃ during winter. The temperature of soil under the periodically frozen layer is about 5℃, if the reactor and the pipeline are well insulated underground, the working temperature can be expected at 15℃ during summer and 10℃ during winter.

Since the OLR from the wastewater is 0.23 kg COD_t /m^3/d, the methane yield is expected to be 0.09 m^3/d at 15℃ or 0.03 m^3/d at 10℃.

4.2.2. Option 2: Two-phased UASB reactor for wastewater and kitchen waste treatment

A two-phased UASB system will be used for the treatment of kitchen waste and wastewater. The mixed kitchen waste and black water will be used for phase I and grey water will be transported to phase II to build a higher substrate level of the influent in phase I (see figure 19). On this demosite, the daily kitchen waste production is c.a. 1.6 kg/d, the VS of the influent in phase I will be c.a. 1.5 kg VS/m^3/d and methane yield is expected to be 0.46 m^3/d at 15℃. Working temperature and HRT are the same as option I.

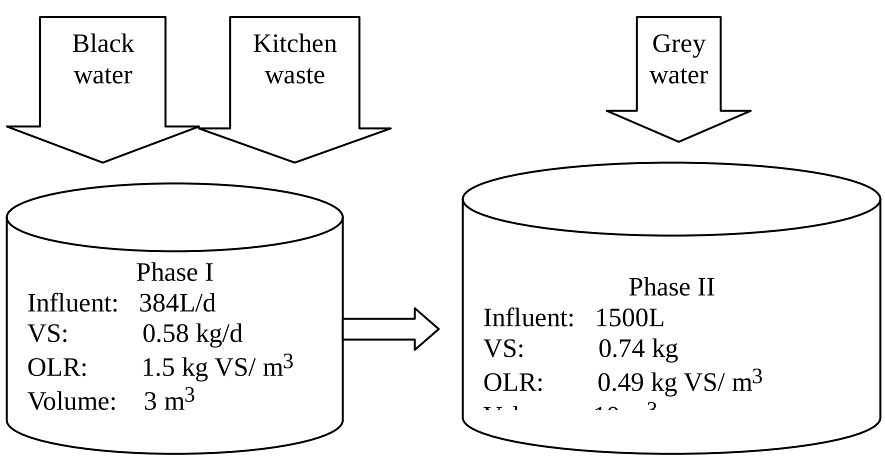


Figure 19 Different OLRs of two-phased UASB reactor

4.2.3. Option 3: CSTR for biogas production based on the wastewater, kitchen waste and manure treatment

The OLR of the reactor is set to be 2 kg VS/ m^3/d. Because the wastewater production is 1.5 m^3, the VS load needs to be 3 kg VS/d. Considering the VS load from wastewater and kitchen waste, the manure added into the reactor will be 8.7 kg/d. HRT needs to be 30 d and the operating temperature will be the same as former options. Based on the methane potential from the assay, the methane yield is expected to be around 0.9 m^3/d at 15℃.

5. Discussion

5.1. Comparison of different options

Option I was designed for the on-site wastewater treatment, therefore the major concern was the organic and nitrogen removal. With a low COD loading of the influent and the modest temperature, the removal was presumed to be 80%.

Option II was much the same as the Chinese typical sewage purification biogas reactor (see figure 10). The major function of option II was to dispose kitchen waste and produce biogas, hence the black and grey waste water were separated to increase the COD level and kitchen waste was added into black water to promote the methane yield. The second phase was to enhance the COD removal and recover methane potential of the effluent of phase I and the grey water. The COD removal of the AD process was expected to be 80% as study shows that using a two-phased UASB could reach 90% removals for black water mixed with kitchen waste at 10℃ with the OLR of 0.56-0.62 kg COD/m3/d and HRT of 3-5 d [37].

Option III is an attempt to utilize the horse manure produced from the demosite. The major constraint of the biogas production from manure was the limited production of waste water which is used to dilute the manure. Meanwhile the 30 d HRT time made the methane yield per volume very low and therefore uneconomical.

5.2. Post treatment and nutrients recovery

The effluent of the anaerobic process is planed to be discharged to the existing oxidation ditch which is to utilize the aerobic environment for the further removal of nitrogen and organics. Currently, the oxidation ditch could reach to the removal of 93% of BOD_7 and 78% of TKN. After the combined aerobic process, over 90% of the COD and total nitrogen will be removed.

Because of the slower process of hydrolysis and degradation of solids at a lower temperature, sedimentation and the formation of sludge are concerns for the reactor operation, especially when kitchen waste and manure were added in. Desludging has to be exercised regularly for the reactors.

During the AD process, part of the nitrogen and most phosphorus are trapped in the form of struvite (NH_4MgPO_4) and part of the nitrogen is in the form of ammonium nitrogen [38]. Because low temperature has a negative influence on ammonification, most of the removed nitrogen in the AD process is in the form of struvite, therefore, it is an optimal choice to apply the removed sludge in the earth field as a useful fertilizer that not only increase the nitrogen content but also improve the soil texture.

5.3. Energy issues and use of biogas

As a none-energy-driven system, the whole AD process in UASB reactors are running without any energy input used to increase the temperature for the reaction or stir. In order to reduce the loss of heat of influent and provide enough insulation, the reactors are better to be built inside the horse stable and underground. However, if the CSTR system is used, some external energy will be needed to drive the stir.

In general, the biogas produced on the demosite could be used for heating and lighting. The production is limited but continuously and under low pressure, therefore a gas tank is needed for gas collection. Meanwhile, desulfurization is also necessary before combustion.

5.4. Uncertainties

Present research has shown the feasibility of using black water and kitchen waste for biogas production at low temperature under laboratory conditions, however, the result of application in reality may differ. The major uncertainty comes from the fluctuation of the COD loading of the influent and the irregularity of the substrate feeding. Meanwhile, ambient temperature change could also influence the temperature of incoming wastewater thus change the operation temperature of the reactor. Other factors such as inhibition from unwanted feedstock, *etc.* could also affect the performance of the reactor. The need to build a demonstration plant to observe more information of the system is in practice.

6. Conclusions

China has abundant experiences in practicing small scale AD process for biogas production. In spite of the various disadvantages from harsh environment including drought and frost, adjusted designs in different areas show profound results in different climate regions. AD reactors are playing a key role in the improvement of rural environment and providing energy for local residents. Meanwhile, studies of small scale wastewater AD process and the combined post treatment in China have revealed the possibility of various onsite organic waste disposal methods.

Despite the cold climate in Finland, it is possible to apply AD process for domestic wastewater and kitchen waste treatment if proper insulation methods were employed. Two UASBs and one CSTR reactors are proposed in three plans based on the different feedstock and functions of the plant. For all the plans, the operating temperature of the reactor is set at 10-15℃ which is the temperature of the influent in winter and summer time, but there are significant differences between the three options in their functions and capacities. Organic loading rate and ambient temperature are the most influential factors for all of them. Due to the low temperature and small amount of substrate added in, methane yields in all the options are limited although the COD removal of the AD process can be expected to 80%. The existed open oxidation ditch is proposed to be used to remove the nutrients left in the effluent and the sludge from the reactors is utilized as fertilizer to recover the nitrogen and phosphorus and improve the soil texture.

Reference:

[1] Seghezzo L., Zeeman G., van Lier J. B., Hamelers H. V. M. and LETTINGA G, 1998. A review: the anaerobic treatment of sewage in UASB and EGSB reactors. Bioresource Technology, vol 65 (3), p175-190.

[2] Rasi S. E. and Rintala J. 2009. Biogas composition and upgrading to biomethane. Jyväskylä Studies in Biological and Environmental Science, vol 202, p76.

[3] Ward A.J., Hobbs P.J., Holliman P.J. and Jones D.L., 2008. Optimisation of the anaerobic digestion of agricultural resources, Bioresour. Technol. **99** , pp. 7928–7940

[4] F., 1994. L'épuration biologique des eaux. Théorie et technologie des réacteurs. Cebedoc Editeur, Liège, 1993, p103 (in French).

[5] Huser B.A., Wufrmann, K. and Zehnder, A. J. B., 1982. Methanothrix soehngenii gen. nov. sp. nov., a new acetotrophic non-hydrogen-oxidizing methane bacterium. Archives of Microbiology vol 132, p1-9.

[6] Ministry of Agriculture, 2007. National Rural Biogas Project Construction Plan 2006-2010. p 12.

[7] Hu Q. C., 2006. The Promotion of Rural Domestic Biogas Plants in P. R. China. Paper presented on First Meeting of Network of Experts on Domestic Biogas, Hanoi.

[8] National Bureau of Statistics, 2007. Chinese Energy Statistical Yearbook 2008.

[9] Kou J. P., Zhao L. X., Hao X. R. and Tian Y. S., 2008. The Status Quo and Trend for Renewable Energy Development in Rural China. Renewable Energy Resources, 2008, 26(3).

[10] National Bureau of Statistics, 2006. Chinese Energy Statistical Yearbook 2006.

[11] National Development and Reform Committee, 2007. Mid-to-long Plan for Renewable Energy Development.

[12] Hao X. R., 2005. Rural Renewable Energy Development in China. Workshop on Rural Energy, Stoves, and Indoor Air Quality in China, Beijing.

[13] Li J. M., Sun Y. F.，Chen X. F.，Zhao Y.J. and Liang B. F., 2005. Standard system for China rural renewable energy development. Transactions of the Chinese Society of Agricultural Engineering, 21(11) p164.

[14] Du Y. Z. and Du J. B., 2005. China Biogas Development Report 2004. China Biogas, 2005, 23(1-6).

[15] Local Standard of Effluent from Biogas Purification Tank in Si Chuan Province (DB51/136-1992). Department of Agriculture of Si Chuan Province, 1992.

[16] Integrated wastewater discharge Standard (GB 8978 1996). National Administration of Quality Inspection, 1996.

[17] Xia B. S., Hu Q. C. and Song L., 2008. Technical Analysis of Designs of Biogas Digesters for Treating Domestic Sewage from Rural Areas. Transactions of the CSAE, 24(11).

[18] Hu Q. C., Wen S. D., Han X. Y and Yan X. Q. 1996. A Laboratory Study on Low Strength Organic Wastewater Anaerobic Treatment by UASB/ITS Reactor. China Biogas, 14(3).

[19] Xiao L. P. and Deng Z. Y., 2005. Experimental Studies on the Treatment of Domestic Wastewater by Using USSB (Up-flow Staged Sludge Bed) Reactor and Aerobic System. Industrial Safety and Environmental Protection, 31(3)

[20] Chen J. J., 2008. Experimental Research on Rural Domestic Wastewater Treatment by ABR. Southwest Jiaotong University.

[21] Fu J. Y. and Dong F. K., 2003. Anaerobic Baffled Reaction Filter (ABRF) for Treatment of Municipal Wastewater (Pilot Test). China Water & Wastewater, 2003(19)

[22] Li X. H., Yang F. L. and Zhang X. W., 2006. Feasibility study of removing organic and nitrogen from sewage water in the UASB/BF system. Environmental Pollution & Control, 2006(05)

[23] Wang C. L., Hu L. X. and QIAN S. C., 2001. Studies on the Treatment of Domestic Sewage by Hydrolytic-aerobic System. Environmental Science and Technology, 2001(02)

[24] Wang C. L., Song T. H. and Gao Y. J., 2005. A waste water treatment technology of low energy consumption. Journal of Changchun Institute of Technology, 2005(04)

[25] Peng Z. Y., 1999. An Integrated Wastewater Treatment System with Anaerobic and aerobic Process. Chongqing Environmental Science, 1999(05)

[26] Qi Y., Chang M. and Koyanagi, H., 2008. Technical Applicability for Decentralized Sewerage Treatment in Township and Rural Area. Water &Wastewater Engineering, vol 24 (18).

[27] Gao Q., Chai X. L., Cheng H. J. and Zhao Y. C., 2005. Comprehensive utilizing of biogas liquid residue. Renewable Resource Study, 2005 (6).

[28] Zhang Q. G., 2005. Biogas Technology and Application. Chemical Industry Press, Beijing.

[29] United Nations's Urban Population, Development and the Environment, 2007. http://www.un.org/esa/population/publications/2007_PopDevt/Urban_2007.pdf, last accesses in August, 2009.

[30] Finnish Environment Administration: Wastewater treatment in rural areas. http://www.environment.fi/default.asp?contentid=306959&lan=EN, last accesses in August, 2009.

[31] Finnish Environment Ministry, 2003: Government Decree on Treating Domestic Wastewater in Areas Outside Sewer Networks (542/2003). http://www.finlex.fi/fi/laki/kaannokset/2003/en20030542.pdf, last accesses in August, 2009.

[32] K. Makowski, Wild M. and Ohmura A., 2005. Diurnal temperature range over Europe between 1950 and 2005. Atmos. Chem. Phys., 8, 6483–6498, 2008.

[33] APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association, Washington, DC.

[34] SFS Standards, 1988. Finnish Standards Association. Determination of chemical oxygen demand (CODCr) in water with the closed tube method, oxidation with dichromate. SFS 5504. Helsinki, Finland: Finnish Standards Association; 1988.

[35] Perstorp Analytical/Tecator AB, 1995. The determination of nitrogen according to Kjeldahl using block digestion and steam distillation. Tecator application note. Hoganas, Sweden; 1995.

[36] Erkki Santala: Finnish regulations, European standards and testing of small wastewater treatment plants. http://www.earthforever.org/pics/p14Finnish_regulations_European_standards.pdf, last accesses in August, 2009.

[37] S. Luostarinen and J. Rintala. 2006. Anaerobic on-site treatment of kitchen waste in combination with black water in UASB-septic tanks at low temperatures. Bioresource Technology, vol 98 p1734－1740.

[38] Loewenthal R.E., Kornmuller U.R.C. and van Heerden E.P., 1994. Modelling struvite precipitation in anaerobic treatment systems. Water Sci Technol, vol 30 p107-116.

Appendix i Financial plan for biogas development in China									
Subareas[i]		By the end of 2005			2006-2010		By the end of 2010		
		Total Rural Household Number (million)	Targeted Group (million)	Constructed units (million)	Total units (million)	Central Gov. Financial Aided Household (million)	Total units (million)	Dissemination Rate in Rural Household (%)	Installation Rate Among Targeted Group (%)
Total		**249.72**	**148.00**	**18.00**	**23.18**	**13.175**	**41.18**	**17.45**	**29.63**
West	Subtotal	***77.62***	***57.08***	***8.71***	***11.32***	***6.40***	***20.03***	***26.51***	***36.18***
	Southwest	50.97	40.50	7.90	6.63	3.75	14.53	29.25	37.16
	Northwest	18.13	10.20	0.60	3.54	2.00	4.14	23.42	41.40
	Minority Region	8.52	6.38	0.21	1.15	0.65	1.36	16.37	21.73
Middle & Northeast	Subtotal	***101.24***	***64.42***	***6.70***	***9.56***	***5.40***	***16.26***	***17.20***	***27.51***
	Southeast Hilliness Regions	25.46	20.92	3.72	3.10	1.75	6.82	28.69	36.63
	River Plain of Huang Huai Hai	64.56	37.60	2.58	5.22	2.95	7.80	12.94	22.13
	Northeast	11.22	5.90	0.40	1.24	0.70	1.64	15.65	31.24
East		70.86	26.50	1.59	2.30	1.375	3.89	5.91	15.85

[i] West includes: Southwest (Guang Xi, Chongqing, Si Chuan, Gui Zhou, Yun Nan, Tibet), Northwest (Shaan Xi, Gan Su, Qing Hai, Ning Xia, Xinjiang and Inner Mongolia) and 11 minority autonomous regions (Enshi in Hubei Province, Xiangxi in Hunan Province, Yanbian in Jilin Province and 8 towns in Hainan). Middle & Northeast include: Southeast Hilliness Regions(Jiang Xi,Hubei, Hu Nan, Hai Nan), River Plain of Huang Huai Hai (He Bei, Shan Xi, An Hui, He Nan)and Northeast (Jilin, Liao Ning, Hei Longjiang). East includes: Beijing, Tianjin, Shanghai, Jiang Su, Zhe Jiang, Fujian, Shan Dong, Guang Dong.