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Prefabricated biogas reactor based system for community wastewater and organic waste treatment in developing regions of Asia

Shikun Cheng, Zifu Li, Heinz-Peter Mang, etc

Centre of Sustainable Environmental Sanitation

University of Science and Technology Beijing , P.R.China

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Introduction

A typical dens populated area in Dhaka, Bangladesh

Biogas septic tank in Dhaka, built by "Practical Action", 10 years ago

Photo taken by Shikun Cheng, 2012

Introduction

- MDG 7 requires achieving a significant improvement in the lives of at least 100 million slum dwellers by 2020 by reducing poverty and improving water and sanitation.
- 1/3 population in Asia can't access to safe and sustainable drinking water,
- 1/2 population in Asia don't have improved sanitary facilities.
- From 48 countries for which data are available throughout Asia-Pacific region, 30 are off-track for meeting the 2015 CO_2 emissions target.
- In China alone, 90.84 million rural people suffer from contaminated water sources.

Appropriate Technologies for Decentralized Systems

- Examples of the simple techniques are grease trap, gravel and sand filtering system, vegetative systems, trash removal, floating and sedimentation, and natural circulation system.
- Selection of appropriate technologies depends on a package of factors, e.g.
  - The population of targeted area
  - Function of township/village/community
  - Terrain, geology feature, climate
  - Discharge requirement
  - Local economic level

Appropriate Technologies for Decentralized Systems

Technology	Description
Biogas septic tank (BST)	The simple septic tank system is the most commonly known primary treatment method for onsite wastewater treatment because of its considerable advantages. Septic tanks remove most settleable solids and - if gas tight sealed -function as an anaerobic bioreactor that promotes partial digestion of organic matter and provides energy in form of biogas. The Imhoff tank with biogas collection is another primary treatment method that can accommodate higher flow rates than the septic tank, but it is less common (May et al., 2009).
Anaerobic baffled reactors (ABR)	ABR is modified from simple biogas septic tank system, ABR could realize biogas recovery. In 1981, the ABR was developed by McCarty and his co-workers to treat high-strength organic loaded wastewater (William et al., 1999). A model for DEWATS is developed in Nepal with ABR and Hybrid Constructed Wetland (HCW). There is high potential of using ABR as primary treatment. ABR is very effective in the removal of organic parameters (Shirish et al., 2009). Moreover, ABR could be filled with carrier materials similar as in Anaerobic Filters (AF) to realize high contaminant removal (Feng et al., 2008).
Membrane biological reactor (MBR)	MBR combines the features of membrane separation and biological treatment technology. It can be regarded as an advanced treatment technology. MBR is not an easy-to-maintain technology and is not ideal for most of rural, peri-urban and slum conditions. MBR mainly suits to the areas where a high effluent standard is required (Adriano et al., 2010).
Constructed wetland (CW)	Today, there is a rising interest in CW all over the world. It makes full use of triple synergy among chemical, physical and biological effect of natural eco-system. Wastewater is purified when passing through a constructed basin filled with coarse sand and gravel, planted by water-tolerant plants like reeds, cattails and other hygrophilous plants, thus imitating natural marshland conditions. CW doesn't treat high-polluted wastewater. Instead, it normally functions as a post- treatment unit.
Sand filtration treatment system	Known as natural treatment systems, sand filtration (mostly buried) systems are regarded as more environmentally friendly final treatment step, more cost effective, and solid waste problem-free in comparison to conventional systems (Kemal and Bilal, 2009).

Prefabricated biogas reactor

- In contrast to traditional on-site constructed brick / concrete type reactor, a prefabricated reactor is produced off-site with materials with special physical properties.
- Normally, this kind of reactor should be:
  - Affordable (in light of lifespan)
  - Convenient (easy maintenance)
  - Collateral (removed and sold second-hand)
  - Transportable (ready-to-assembly packaging)
  - Custom sizing (meet the diverse needs)

Applicability

- Prefabricated biogas reactors are suitable for places where:
  - The ground water level is high; in coastal areas where it is difficult to construct traditional brick, stone, concrete or molded reactors; where quality of reactor construction cannot be controlled but gas- and water-tightness should be absolutely guaranteed;
  - The site is located in remote mountain areas, where it is difficult to provide and transport conventional construction materials;
  - The site is short of conventional construction materials and specialized labor force, which leads to increasing construction cost or extended program overheads due to repeatedly required training sessions;
  - Where residential areas are modified and rebuilt as a result of Urban or Rural Reconstruction and Land Reform measures, or inheritance, which affects the permanent siting of conventional reactors.

Production alternatives

- Hand-made
- Factory Production

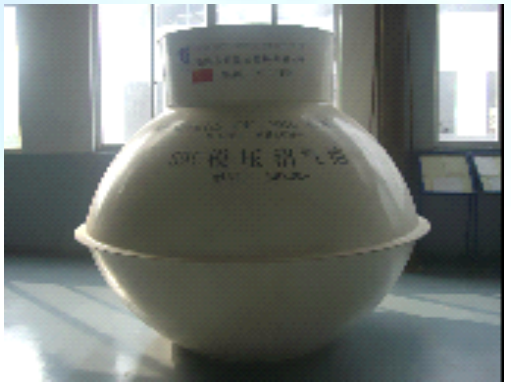
Source: China Chengdu Hongqi Company
(Left: as done before;
Right: nowadays manufacturing)

Reactor types

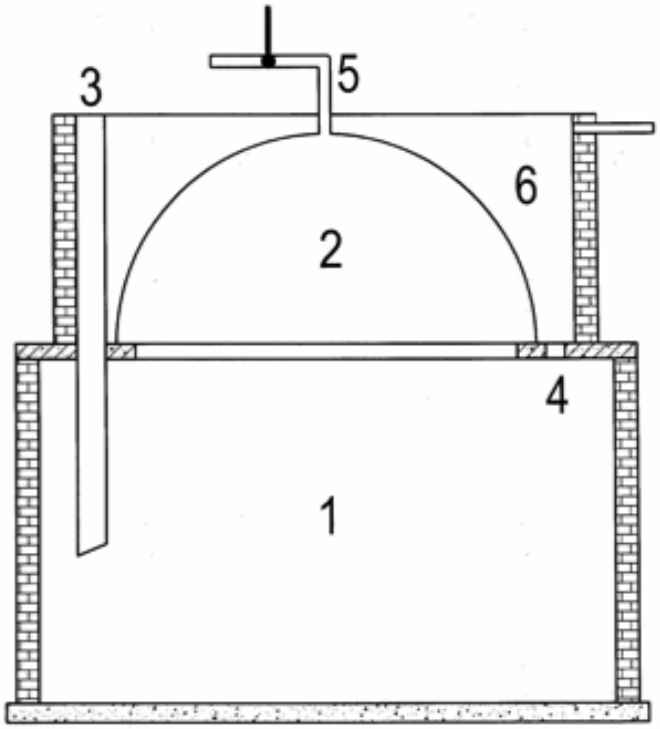
- Soft reactors (bag reactor)
  - PVC (Polyvinyl Chloride)
  - PAMM (Polymethyl Methacrylate)
  - LDPE (Low-Density Polyethylene)
  - PE (Poly Ethylene)
- Hard reactors
  - FRP or GRP (Glass Fiber Reinforced Plastics) or “Composite”
  - Hard PVC
  - HDPE (High-Density Polyethylene)
  - ABS (Acrylonitrile Butadiene Styrene)
  - Ferro- / Bamboo Cement
  - PP (Polypropylene)
  - LLDPE (Linear Low Density Polyethylene)
- Portable / assembled reactors

FRP reactor

- FRP or GRP or GFRP (Glass Fiber Reinforced Plastics)



FRP reactor (upper part only)



Source: Chengdu Hongqi Company

FRP reactor

- Light weight, with a weight of only 1/10 compared to concreteor brick reactor;
- Low coefficient of heat conductivity, with a good insulation effect - suitable for cold areas;
- Good corrosion resistance against all kinds of organic acids;
- High strength, good resistance, good gas tightness, water-proof;
- Long service life and low maintenance cost: life span of FRP reactor could reach 20-30 years;
- High quality and steady quality if FRP reactor is “press" manufactured, not “hand made”;
- High mechanical strength for pressure and tension, which is much higher than required in an hydraulic reactor system;

FRP reactor

FRP reactor in Bangladesh, half is from China, the other half is duplicated and domestic production.

Source: Shikun Cheng

FRP reactor

Viet Nam models

FRP reactor

FRP reactor workshop in Bangladesh, hand-made

Source: Shikun Cheng

FPR mould

For onsite brick-concrete construction to shorten construction period and improve construction quality.

Source: Anhui Chonglang Company, China

ABS reactor

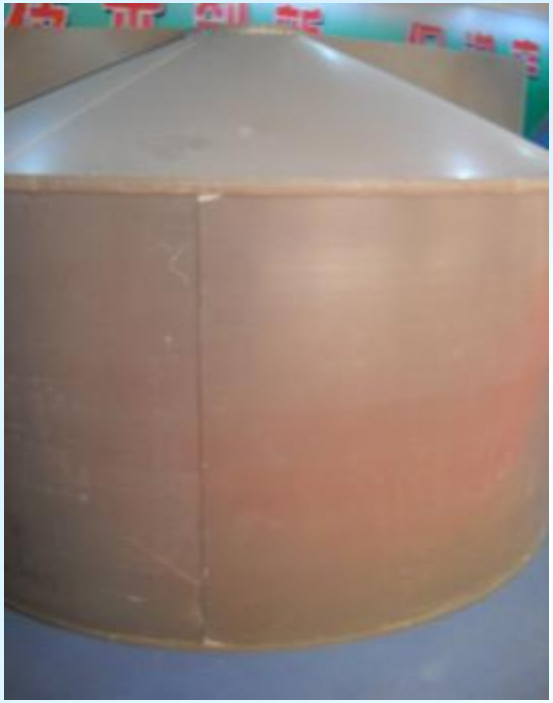
	ABS reactor	FRP reactor	Concrete reactor
Mode of production	Factory production, mechanically suppressed	Workshop production by hand	Individual civil engineering construction
Tightness	Good sealing, highly polished inside	Influenced by the operators, hidden trouble of air leakage	Air leakage likely
Weight	About 80kg	About 160kg	About 8000kg
Transportation	Well matched, light weight, low transportation cost	Handmade, big loading gap	Field construction
Production quantity	40 sets, 4 people/day	1 set, 2 people/day	3-7days,1 mechanic and many unskilled laborers
Mechanical properties	High strength, impact resisting, strong toughness	Good strength, ordinary impact force	High strength, weak toughness
Service life	20y	20y	Within 20y
Maintenance	no	Some check for cracks	Internal check every 4-5y
Construction and installation	Half a day, 2 people	Half a day, 2 people	3-7 days, many people

Source: Anhui Chonglang Company, China

HDPE reactor

Source: C.V.Krishna, India

PVC reactor



Hard PVC reactor

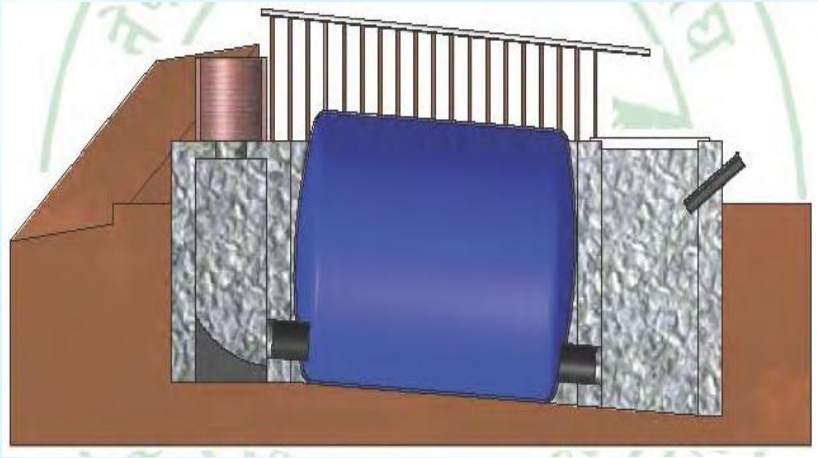
Soft PVC reactor

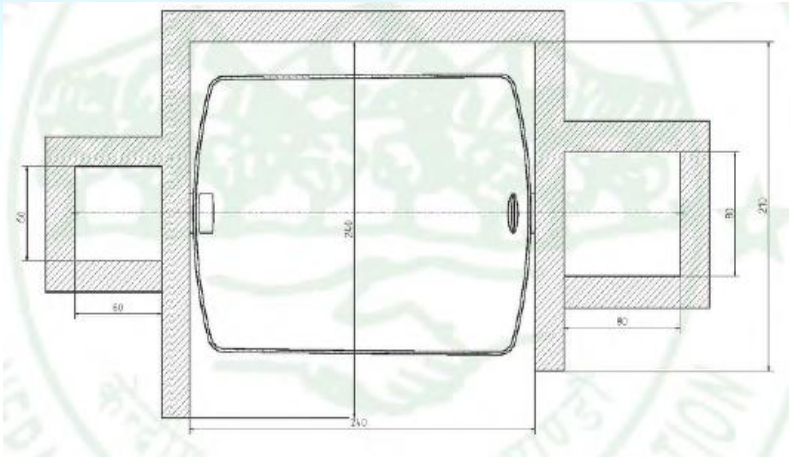
Source: Heilongjiang Jianxin Company, China (Left)

Bag reactor

Source: Malaysia, produced by Shenzhen Puxin Company, China

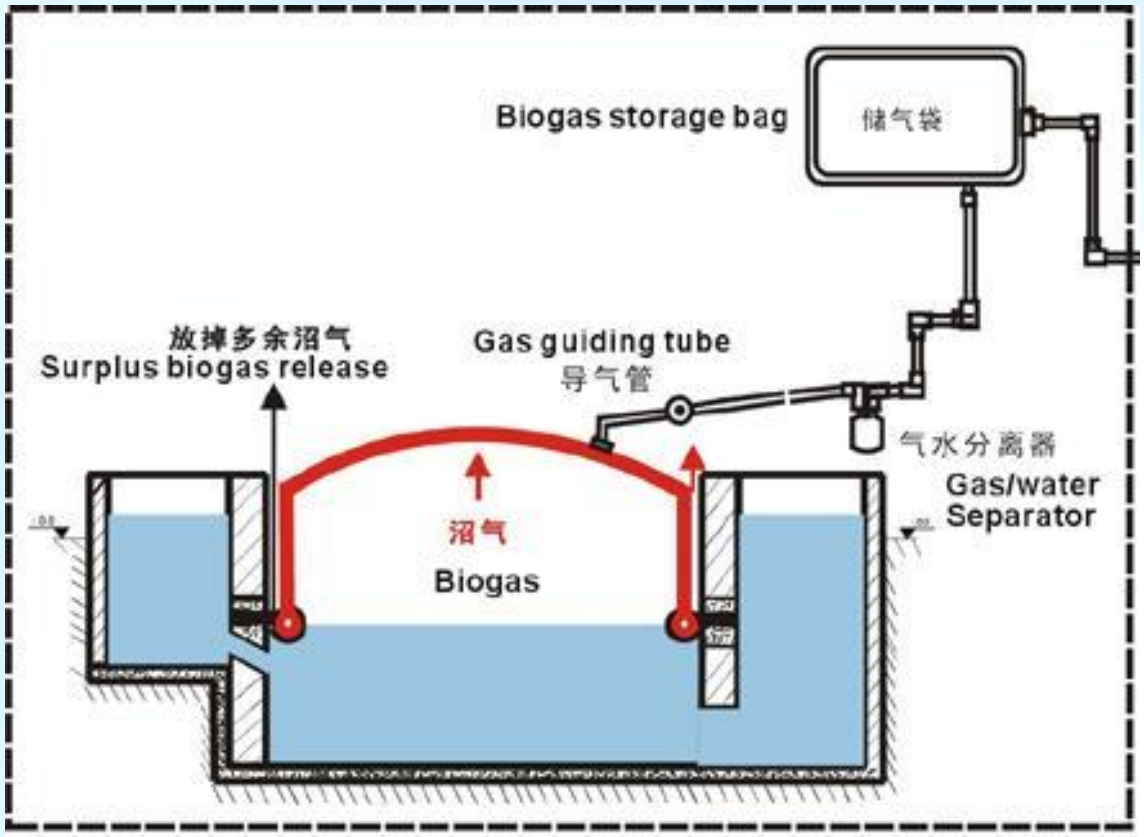
PVC soft reactor

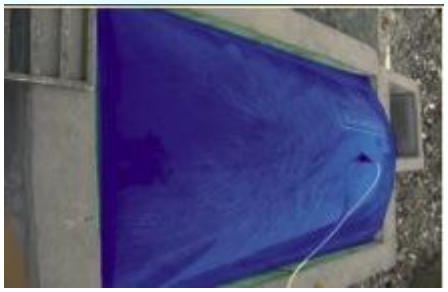


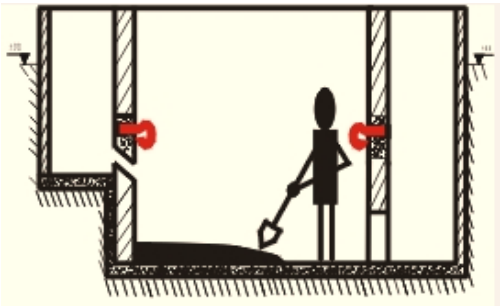


reactor inside of clay box structure

PVC reactor (partly)







Principle sketch of water-sealed self-regulating suspended type soft reactor

Source: Chengdu Datangren Company, China

PVC reactor

Source: Heinz-Peter Mang

Soft reactor

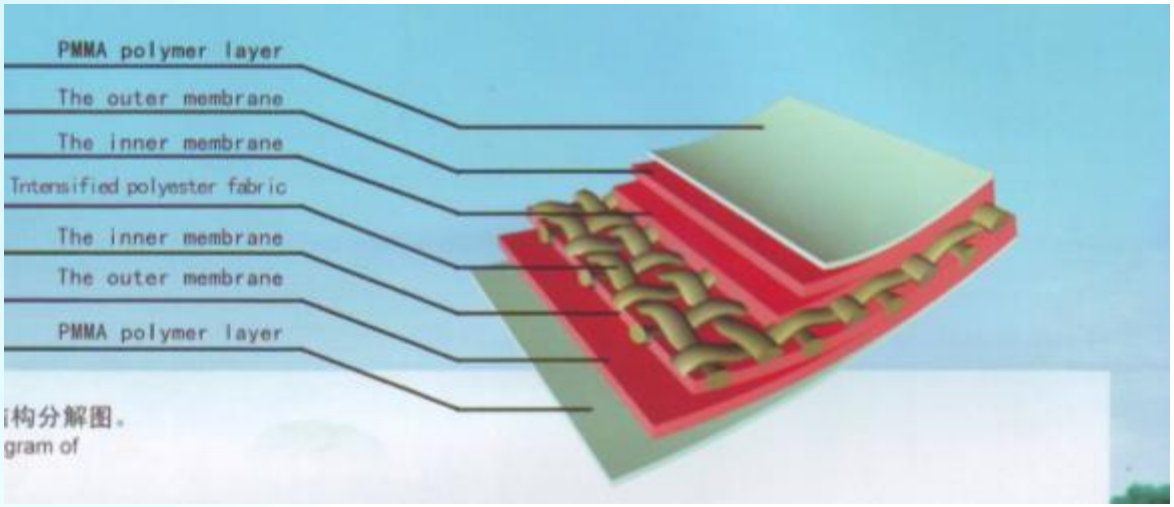
Item			Enterprise standard		Test result	
			Suspended combination type	Full-sealed bag type	Suspended combination type	Full-sealed bag type
Product performance	Bearing capacity ,Pa ≥		4000	4000	5800	4200
	Tearing strength , N ≥		180	180	378/336	378/336
	Air tightness(4ka,24h) ≤		3			
	Acid-and alkali-resistant performance		Free of deformation, peeling, softening or crack		Free of deformation, peeling, softening or crack	
	Puncture resistant performance(broach of 50g free falling from1000/600mm high)		Not pierced		Not pierced	
Material performance	Tensile strength MPa	Longitudinal ≥	15/13	15/13	28.7/26.47	23.4/19.9
		Horizontal ≥	15/13	15/13	28.7/26.47	23.4/19.9
	Right angle facture Strength KN/M	Longitudinal ≥	66	62	92.6	82.7
		Horizontal ≥	62	60	98.8	85.4
	Elongation at break %	Longitudinal ≥	389	389	368	363
		Horizontal ≥	392	392	378	375

Source: Chengdu Datangren Company, China

Soft reactor

Item	Traditional biogas reactor	Plastic software biogas reactor
reactor construction cycle	10-20days	1-3days
reactor construction cost	Relatively high	Reduced by about 20%-30% of traditional reactor
reactor performance	Hardware，fixed，unmovable，easy to leak	Software，movable，well sealed
Service life	Long	Long
Shape requirement	Deep，inflexible	Hollow，inflexible
Biogas generation rate	Average	High and stable it can remain normal gas generation in winter if insulation measures are taken
Surplus gas	Cannot store surplus gas of biogas nor be movable	Can store surplus gas and be movable
Combustion power	Flame normally 15cm high with light firepower	Flame as high as 15-35cm with strong firepower
Scum formation on surface	Forming scum and difficult to solve	Free of shell formation normally
Feeding and discharging	Difficult in feeding and discharging.Person is needed to go down the reactor for discharge, easy to get poisoning	Easy and convenient for feeding and discharging. No person is needed for discharge, solving the problem of having difficulty in.
Technology and process requirements	Master air-tightness process. Understand engineering drawing. Master brick arch technology. Understand diagnosis and treatment of biogas leakage and water leakage of reactor as well as protection. About three months are required for training.	Easy to master. Operation can be conducted in short period of time. Success rate of reactor construction reaches by 100%.
Maintenance service	When biogas reactor is damaged or biogas leaks, it is difficult in repairing, which will influence the normal use of reactor.	When biogas reactor is damaged or biogas leaks, it is difficult in repairing, which will influence the normal use of reactor.
Industrialization and scale production	Incapable	Capable

PAMM soft reactor



Source: Fujian Sijia Company, China

Portable assembled reactor

1.6m×1.3m
V=3m3

2m×2m
V=5m3

Source: Jiangxi Gongchuang Company, China

Portable assembled reactor

Volume=2.5m3;

Material: LLDPE

Source: Exhibition in Spain, digester produced by Shenzhen Puxin Company, China

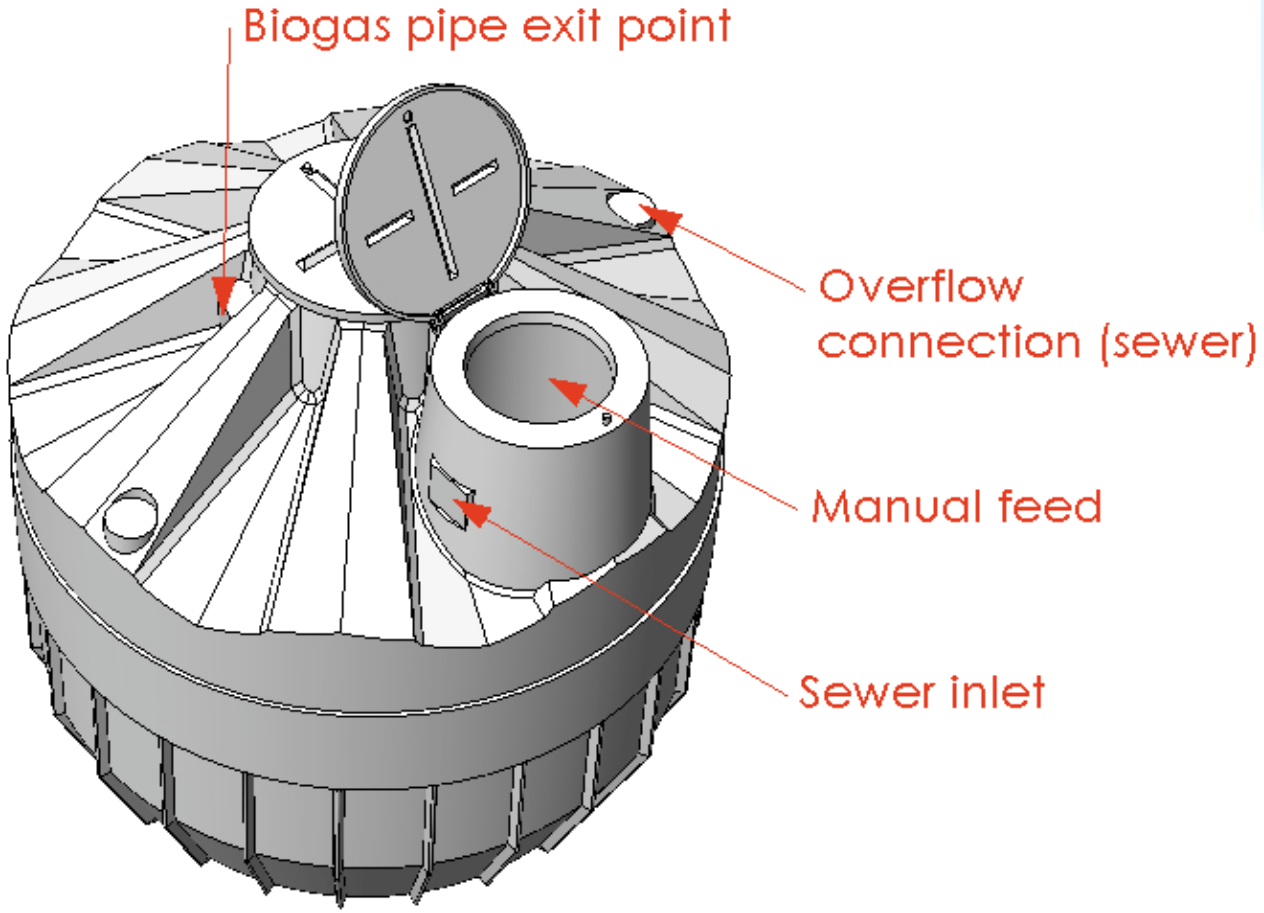
Portable assembled reactor

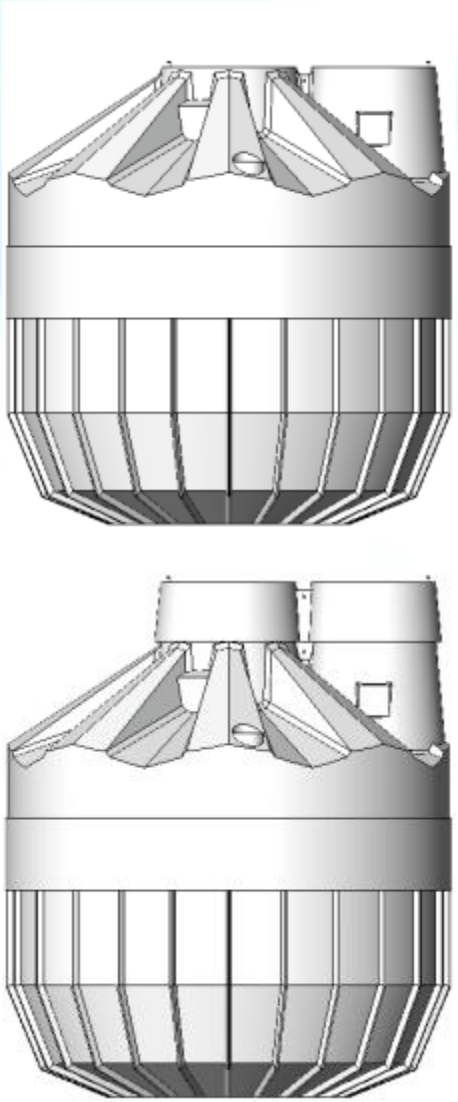
1. Gas pipe
2. Upper
3. Seal
4. Bottom
5. ∅110 Seal Ring
6. Flange
7. Connecting pipe
8. 90° elbow
9. Butterfly gate
10. blind plate
11. ∅200 Seal Ring
12. Inlet
13. Cover
14. Outlet
15. Slag outlet

Source: Shenzhen Puxin Company, China

South African model

Source: AGAMA Biogas (Pty) Ltd, South Africa





Source: AGAMA Biogas (Pty) Ltd, South Africa

Tanzanian model

Source: SimGas, Tanzania

Indian model

Features:

1) Twin tank design for two stage digestion.
2) Wide mouth feed chamber for convenience.
3) Unique mixing system without power consumption.
4) No operational problems.
5) Compartmental design.
6) Less space requirement.
7) Portable and aesthetic looks

Source:
Dr. Johny Joseph
Scientist, BEEC, IICT

Cambodian models under testing

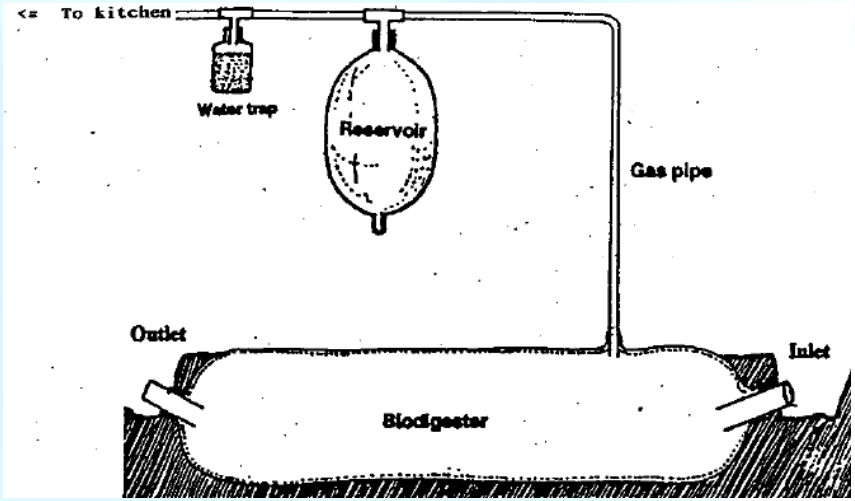
Source: CARDO, Cambodia

Bamboo cement reactor

Source: Grameen Bandhu Biogas Plant, India

Ferro cement reactor

Polyethylene tube reactor



Mekong Delta, Viet Nam

Polyethylene tube reactor

FRP in Cuba

Source: Heinz-Peter Mang, Cuba

Conclusions

- Decentralization is a promising way for wastewater and waste management in urban slums.
- Prefabricated biogas reactors possess obvious advantages over traditional reactors, such as easy maintenance, short construction period, good air tightness, easy transportation.
- Motivation of users could be a challenge for the commercial dissemination of prefabricated reactors.

Thank You Very Much for Your Attention!

Room 12 14, Tuhuan Lou,

Xueyuan Road 30, Haidian District, Beijing, 100083, P.R.China

Phone / Fax: +86 10 6233 4378

Director: Prof. Dr. -Ing. Zifu Li

Manager: Dipl. –Ing. Heinz-Peter Mang

http://www.susanchina.cn