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Short Communication

Prefabricated biogas reactor-based systems for community wastewater and organic waste treatment in developing regions

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ABSTRACT

Population densities in cities of developing countries are much higher than in other parts of the world, and the predominance of poverty in urban slums is ubiquitous throughout the region. In many urban areas, the lack of wastewater and waste management continues to be a huge challenge for environment and health protection. Decentralized approaches are proposed to provide practical, alternative options for sustainable urban wastewater and waste management in urban conditions. Conventionally, on-site constructed brick/concrete biogas reactors are the most used models. However, long construction periods, quality issues and leakage of biogas are often the disadvantages of construction design. In contrast to these systems, prefabricated biogas reactors can be produced off-site from different kinds of material. In this paper, prefabricated biogas reactor and treatment systems will be discussed, which could be applied in different developing countries. Meanwhile, some existing cases in China, Indonesia and South Africa are presented to show clear scenarios.

Key words | DEWATS, prefabricated biogas reactor, slum, wastewater and waste management

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INTRODUCTION

At the turn of the century, the Millennium Development Goals (MDGs) unveiled a special horizon – one that the entire developing world has been tasked to arrive at by 2015. The MDGs become the parade-horse of the international community with respect to poverty eradication (ADB/UNDP/UNESCAP/WHO 2006). 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. Up to now, although the world has met the MDG drinking water target, five years ahead of schedule, there are no reasons to relax. Projections indicate that in 2015 more than 600 million people worldwide will still be using unimproved water sources (UN 2012).

Rapid urbanization in developing countries creates massive demand for basic infrastructure in cities. The urbanization is attributed to natural increase and rural–urban migration. The rate of urbanization often exceeds the rate of economic growth. As a result, infrastructure development lags behind the population growth, particularly in the low-income areas (Konteh 2009). Population increase in most cities is projected to be highest in slums (Paterson *et al*. 2007). A third of the urban population in the developing countries is estimated to be living in slums, with the highest number in sub-Saharan Africa, where 62% of the urban population lives in slums (UN-Habitat 2009, 2010).

Providing reliable and affordable wastewater and waste treatment systems is a challenge in many parts of the world. Poverty, high density, the absence of utilities and lack of infrastructure are common features of urban slums. The environment of slums is extremely

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unhygienic as they are located at neglected sites such as solid waste dumps, open drains and sewers, low land, embankments, and often along the rail lines (UN-Habitat 2003). Due to the high population density and overcrowding in slums, the potential spread of diseases is usually much greater than in less crowded neighborhoods.

To develop a sustainable urban wastewater and waste management platform for this situation, a decentralized approach for waste and wastewater treatment for biogas production and resource recovery is proposed as a practical option. Centralized wastewater treatment systems depend on sophisticated technologies and skilled manpower for their operation and maintenance (O&M). They require huge investment capital and recovery mechanisms of significant O&M costs (Giovanni *et al*. 2012). Therefore, decentralized wastewater treatment systems (DEWATS) could be beneficial in developing countries, allowing locals to improve their situation when there is a lack of action or capacity of the governing body (Green & Ho 2005).

APPROPRIATE TECHNOLOGIES FOR DECENTRALIZED SYSTEMS

Slums create their own simple wastewater management techniques to improve their living conditions. Examples of simple techniques are grease traps, filtering systems, vegetative systems, trash removal and natural circulation systems. DEWATS are ideal for treating domestic wastewater of small cities, towns and townships as well as suburbs of big cities without sewage pipeline networks. Selection of appropriate technologies depends on a number of factors: for example, population density in the targeted area; economic level and activities; work performance of local authorities in township, village or community; terrain; geology features; climate; and last but not least the wastewater discharge requirements. DEWATS are based on a modular technical configuration concept. Appropriate combinations of treatment modules can be selected, depending on the required treatment efficiency, costs, land availability and other relevant issues for specific locations. Typical technologies for DEWATS are presented in Table 1.

Table 1 | Typical technologies for DEWATS

Technology	Description
Biogas septic tank (BST)	The simple septic tank system is the most commonly known primary treatment method for on-site wastewater treatment. 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 the form of biogas. The Imhoff tank model 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 the simple septic tank system and could – if gas-tight sealed – be used for biogas recovery. In 1981, the ABR was developed by McCarty to treat wastewater with extremely high organic loads (William & David 1999). A model developed in Nepal consists of ABR and hybrid constructed wetland (HCW). ABR has good potential for use as primary treatment. It is very effective in the removal of organic parameters (Shirish *et al*. 2009) and could be filled with carrier materials similar to an anaerobic filter (AF) to provide highly efficient 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 rural, peri-urban and slum conditions. MBR mainly suits areas where a high effluent standard is required (Adriano *et al*. 2010).
Constructed wetland (CW)	CW makes full use of a triple synergy among chemical, physical and biological effects of natural ecosystems. Wastewater is purified when passing through a constructed basin filled with coarse sand and gravel, and planted with water-tolerant plants like reeds, cattails and other hygrophilous plants, thus imitating natural marshland conditions. CW does not treat very polluted wastewater. It normally functions as a post-treatment unit.
Sand filtration system	Known as natural treatment systems, sand filtration (mostly buried) systems are regarded as an environmentally friendly final treatment step, which is cost effective, and free of problems from solid waste generation – compared with conventional systems (Kemal & Bilal 2009).

JUSTFICATIONS FOR PREFABRICATED SYSTEMS AND COMPONENTS

Traditional wastewater and waste treatment systems are usually built with bricks and reinforced concrete, materials which are widely available and low cost. Movable and corroding parts should be avoided, if possible by gravity flow. Low investment and operation costs, owner involvement for cost saving, convenient maintenance, biogas production and sludge recycling are the main features of the traditional process. However, long construction time, quality issues and leakage of biogas are often the disadvantages of the construction design. Prefabricated modules were introduced in recent years. Prefabricated systems have some obvious advantages over the traditional ones: (1) the final quality is better due to industrial style quality control; (2) they bear sufficient mechanical strengths with good air tightness and a long service-life; (3) under normal conditions a good insulation maintains a relatively stable temperature inside the reactor; (4) the light weight facilitates easy transport; and (5) as the systems and/or modules are manufactured off-site, the installation period is short.

Prefabricated systems and components are suitable for the following situations:

- High ground water levels: in coastal areas where it is difficult to construct brick, stone, concrete or molded reactors; where the quality of reactor construction cannot be controlled but gas- and water-tightness should be absolutely guaranteed.
- Locations in remote/mountainous areas: where it is difficult to provide and transport conventional construction materials.
- Site with shortages in conventional construction materials and specialized labor force: to avoid increased construction cost or extended program overheads due to repeatedly required training sessions.
- Where residential areas are modified and rebuilt as a result of rural reconstruction and land reform measures, or inheritance, which affects the permanent siting of conventional reactors.

CASE 1: CHINA

China plays a leading role in the sector of low-cost biogas reactors as well as the prefabricated biogas reactor industry. In China, prefabricated reactors are also called commercialized reactors. The initial development of prefabricated reactors aimed at treating animal or human manure. Since the 1980s, China has developed many kinds of commercialized or semi-commercialized household biogas reactors, such as the PE (polyethylene) reactor, semi-hard plastic reactor, iron reactor, GRP or FRP (glass-fiber reinforced plastics) reactor, GRC (glass-fiber reinforced composite) reactor, ABS (acrylonitrile butadiene styrene) reactor, ferro-/bamboo cement reactor, and the wire mesh cement prefabricated reactor (Zhao 1995; Liang *et al.* 1997). Since 2000, prefabricated reactors have entered the real commercial stage, and a number of manufacturers have started businesses. Currently, prefabricated reactors are available as FRP reactors, soft material reactors and plastic material reactors (CAREI 2011). Typical prefabricated reactors are presented in Figure 1 and Table 2.

As for wastewater treatment, China launched a series of plans and regulations to control wastewater discharge, one of which explicitly stipulated that dispersed settlements without access to municipal sewage collection systems should adopt an on-site wastewater treatment approach to

Figure 1 | Typical prefabricated reactors in China (from left to right: FRP, soft material and plastic material).

Table 2 | Classification of prefabricated reactors by China Association of Rural Energy Industry (CAREI)

Type	Chosen material	Description
FRP reactor	FRP (glass-fiber reinforced plastics)	Representative for prefabricated reactors
Soft reactor	For example: PVC (polyvinyl chloride), PAMM (polymethyl methacrylate), LDPE (low-density polyethylene), PE (polyethylene)	Also called bag reactors in other countries, because it looks like a big soft bag
Plastic reactor	For example: hard PVC, ABS (acrylonitrile butadiene styrene), PP (polypropylene), HDPE (high-density polyethylene), LLDPE (linear low density polyethylene), DCPD (dicyclopentadiene)	A hard reactor in contrast to soft reactor

meet the national discharge standard. Hence, prefabricated wastewater treatment facilities entered the market (see Figure 2). For such a system (Figure 2 left), micro-power is installed between 0.04 and 0.075 kW, serving a population of less than 30, while for larger populations up to 1,500, installed power is 2.88 kW (Figure 2 right). Removal efficiency of COD, SS and TN of such a system can reach 90, 85 and 60%, respectively.

CASE 2: INDONESIA

Indonesia is one of the leading countries with a large number of DEWATS. In 2010 the Indonesian government launched a special budget line from the national budget through the Settlement Sanitation Development Acceleration Program (PPSP), which encourages local governments to implement a community-based sanitation (CBS) like service package in a larger scale of up to 5000 units in over 300 cities until 2014. The population served by DEWATS systems is already larger than the population served by centralized systems in Indonesia and will increase exponentially until 2014 (Ekasanti 2012; Miller 2012). Prefabricated DEWATS in Indonesia is shown in Figure 3 and conventional and prefabricated wastewater treatment facilities are compared in Table 3.

CASE 3: SOUTH AFRICA

On 10 August 2011 the first two prefabricated DEWATS modules were installed in the Frasers informal settlement of eThekwini Municipality, South Africa. They are treating domestic wastewater from a community ablution block serving 75 households. On average each household consists of 5 to 6 people. As most of the existing scattered pit latrines do not work anymore and the public sewer line ends 2 km away from the settlement, the local responsible department provided residents with communal ablutions blocks, i.e. standard container with toilets, urinals, showers and basins on five different sites. The wastewater is treated in decentralized septic tanks. No effluent goes to any water body. The treated wastewater flows into evapotranspiration areas. Three of the five treatment systems are designed

Figure 2 | Low-power prefabricated wastewater treatment equipment in China.

Figure 3 | Prefabricated DEWATS in Indonesia.

Table 3 | Comparison of implementing wastewater treatment facilities between conventional and prefabricated with FRP in Indonesia (Ekasanti 2012)

	Conventional	Prefabricated
Site selection	Fixed building	• Can be added/removed; easy to meet changing demand and user numbers • High mobility, flexible, can be relocated
Site condition	Complicated construction method when meeting difficult soil conditions	Easy to install in any soil condition
Quality control	Need high skills to supervise the implementation on site to keep the quality required	Quality control can be done off site in the workshop during production to meet the standard
Construction period	70–90 days construction	3–7 days installation
Maintenance	Difficult to find the leakages and costly to repair	Easy to repair

according to BORDA's DEWAT systems, while for the first time two different prefabricated concrete modules were installed, manufactured and assembled by a local company. Transportation and installation of prefabricated packages are shown in Figure 4.

In addition to the improvements in the informal settlement, the old and unhygienic toilets at the local primary school with 330 learners will be replaced by robust prefabricated toilets. The wastewater treatment system will include a biogas reactor, which provides the school kitchen with

Figure 4 | Transportation and installation of prefabricated packages in South Africa.

energy for cooking. This helps to partly substitute the currently used liquefied petroleum gas (LPG).

CONCLUSIONS

The concept of decentralized technologies for wastewater and waste management aims at the development of wastewater systems that are financially more affordable, more socially responsible and more environmentally benign than conventional centralized systems. Decentralization is a promising approach for wastewater and waste management in urban slums.

The technology of DEWATS integrates a package of anaerobic treatment and natural treatment systems. This paper discusses prefabricated biogas reactor-based systems for wastewater and waste treatment, which could replace traditional, on-site constructed brick and concrete biogas reactors. Prefabricated biogas reactors possess obvious advantages over traditional reactors, such as easy maintenance, short construction period, good air tightness and easy transportation. China leads the world in prefabricated biogas reactors, for which available materials are FRP, soft material and plastic material; prefabricated DEWAT systems were tested and disseminated by BORDA in several countries such as South Africa and Indonesia; they have proved to show great potential in developing regions.

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