"Municipal Wastewater Treatment by Pilot Scale Immobilized Cell Reactor"

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Poster Presentation

Abstract

A pilot plant was studied to verify the effectiveness of immobilized cell bio-reactor (ICBR) wastewater treatment technology in treating municipal wastewater (sewage). The system consist of 3 types of unit operations; namely anaerobic reactor, fluidized immobilized cell carbon oxidation (FICCO) reactor and the ICBR. Activated carbon was used as the medium to immobilize microbes in the ICBR in order to have enhanced enzymatic activities, which is essential for the efficient biological treatment of wastewater. The activated carbon had a surface area of approximately 220 m^2/g, higher than that of normal activated carbon. The treated wastewater reached Class A quality with a high percent reduction in BOD (94.3%), COD (97.8%), TSS (98.6%), ammoniacal nitrogen (91.2%) and oil & grease (99.0%). Such impressive results indicated that this technology is indeed effective for municipal wastewater treatment and has the potential to be used in the urban areas where land price and improve water quality are important. Other additional benefits of this technology include less land space and energy requirement, high quality treated effluent, low sludge generation and possible reuse of the treated water.

Keywords: Bioreactor, Effluent Regulation, Immobilized Cell, Municipal Wastewater

INTRODUCTION

Despite the importance of water as a valuable life supporting resource, it is under continuous threat as a consequence of climate change, booming population, industrial activities, and generation of huge amount of waste (Jhansi and Mishra 2013; Ouyang 2005; Battaglin et al., 2007). Due to the drastic improvement of living standards, generation of emerging pollutants has also increased from many activities (Trépanier et al. 2002). On the other hand, water resource is becoming scarce day by day (Esteban and Miguel 2008). Therefore, it has become essential to treat the wastewater and reuse it as much as possible. Though wastewater reuse was initially preferred for agricultural use (Angelakis et al. 1999; Fatta-Kassino et al. 2011; Pedrero et al. 2009), the reuse of wastewater for urban and industrial purposes has now become paramount in several countries. However, feasibility of reclaimed water for municipal and industrial applications is dependent upon the level of wastewater treatment (Kellis et al. 2013).

The most common target of the developing nations is to treat wastewater by conventional methods. There are three distinct stages of conventional wastewater treatment and the effluent quality varies in these stages (Kellis et al. 2013). In the primary stage, basically suspended solids are removed (Topare et al. 2011) for which sedimentation process is used (Spellman 2000). In the secondary stage, removal of biodegradable organic matters is targeted (Topare et al. 2011) using bacteria to decompose the organic matters (Henze and Harremoë 1983). Removal of nutrients bacteria and toxic compounds are the main objectives of tertiary treatment (Prabu et al. 2011).

There are many methods and technologies available for wastewater treatment. The oldest technology still available today is the slow sand filtration (SSF) which has been used in North America and Northern Europe quiet successfully to treat comparatively low contaminated surface water (Slezak and Sims, 1991). The most common natural technology to treat municipal wastewater is wetland (Su et al. 2011) which, if properly designed, can be very effective for wastewater treatment (Baker and Richards, 2002). For developing countries lagoon or wetland is one of the most viable wastewater treatment technologies (Jhansi and Mishra 2013) which allows for total system recovery (Rose 1999). If there is little access to land then anaerobic digestion technology can be sustainable which is quiet flexible to implement as a small or large scale system (Jhansi and Mishra 2013). Soil Aquifer Treatment (SAT) is a low-tech, easy to operate and inexpensive geo-purification treatment system which is also valuable to recharge groundwater (Jhansi and Mishra 2013). However, contamination of groundwater is a concern for such a system.

Due to the increased contaminants identified in the water, scarcity of water and rapid growth of amount of emerging industrial activities, conventional treatment technologies are inadequate to meet the demand of improved treated water (Zhou and Smith 2002). Among the advanced treatment technologies, UV irradiation, membrane filtration and advanced oxidation processes (AOPs) are of great potential alternative technologies which can provide better water quality to sustain life (Zhou and Smith 2002). Physio-chemical techniques, such as chemical precipitation, coagulation–flocculation, ion exchange and flotation are being used for removing heavy metals from industrial wastewater among which lime precipitation has been described as a very much efficient way to treat inorganic pollutants (Kurniawan 2006).

Biological approaches for wastewater treatment are preferred as it involves less chemical use i.e. environment friendly and also cheaper than other methods (Ishak et al. 2012; Mello et al. 2010; Mazzeo et al. 2010). Microbial enzymes are used for decolourization process in distillery wastewater treatment (Pant and Adholeya 2007). For highly concentrated waste streams, activated sludge is an excellent biological mean to give proper treatment to the wastewater (Mitchell et al. 2013). The biological treatment process is also being upgraded e.g. algae-bacteria system is incorporated in the biological treatment process (Su et al. 2011). To retain biomass Membrane bioreactors are an excellent process which is actually a combination of activated sludge process and membrane filtration (Melin et al. 2006). To treat domestic sewage, MBR has a wide range of applicability (Mittal 2011). In this process, bio-solids are separated with a polymeric membrane based on microfiltration or ultrafiltration unit in the MBR process whereas; in conventional activated sludge process gravity settling process is used. However, sustainability of a wastewater treatment technology depends on several factors such as environmental, societal and economic considerations (Muga and Mihelcic 2008).

Presence of air is essential in the aerobic treatment process where microorganisms (aerobes) use free oxygen to convert organic substances into carbon-di-oxide, biomass and water. On other hand the anaerobic processes take place in the absence of air and microorganisms (anaerobes) which do not require air (molecular/free oxygen) convert organic compounds. In anaerobic treatment the ultimate products are carbon dioxide gas, methane and biomass (Mittal 2011). To construct multi-stage filtration (MSF), combination of slow sand filtration (SSF) and coarse gravel filtration (CGF) is required. It is an excellent solution for many rural communities, towns of medium and small size, where chemical treatment is not feasible (Sánchez 2006).

Alternative treatment process came into dire need to treat in situ wastewater with low cost and high efficiency. The attached growth systems gave excellent support to this need (Loupasaki and Diamadopoulos 2013). High removal efficiencies of COD, BOD_5 and NH_4-N can be obtained in the attached growth ponds (AGP) than in the conventional waste stabilization ponds (WSP) (Zhao and Wang 1996). The main advantage of attached growth systems is that their hydraulic retention time is short and they yield a high number of microorganisms which results in high removal rates (Loupasaki and Diamadopoulos 2013; Yamaguchi et al. 1999). Inert materials (rock, slag, plastic etc.) are used where microorganisms are attached to develop biofilm (Hsien and Lin 2005) containing extracellular polymeric substances produced by microorganisms (Metcalf 2003). Activated carbons, nanomaterials are also being tested and occasionally used for further purifying of the conventionally treated wastewater. Use of such adsorbents with high surface area has the potential to significantly reduce the size of the treatment plant. Though the main obstacle remains to reduce the cost of the novel nano-adsorbents, researches show promising use of the nano-materials for immobilization of microbes to enhance the performance of the biological wastewater treatment facilities.

Sewage water treatment is very important to ensure the environment does not suffer from the effects of manmade wastes. Sewage water treatment is needed where a community is present and is especially more important in places with high population density. However it is not always easy to implement conventional sewage treatment plants (STP) due to various factors, such as allocated site size, land conditions, odour restrictions, power requirements and many more. Therefore, this study was conducted to find efficient ways to use immobilized cell bio-reactor (ICBR) to treat the municipal wastewater in urban areas where land price is very high but protection of the river system is also important.

2.0 Methodology

2.1 Wastewater Characteristics

The pilot study was conducted to test its performance to meet the local wastewater quality specification as set by the National Water Services Commission (Suruhanjaya Perkhidmatan Air Negara, SPAN). The system was designed to meet the effluent quality specifications stipulated in Standard A of the Environmental Quality Act of Malaysia (Table 1). The wastewater was tested against the 5 parameters as listed in Table 1, where the mean influent quality is also given.

Table 1: Wastewater Characteristics and Allowable Effluent Standards

Pollutant	Concentration (mg/L)	
	Mean Influent	Standard - A
Biochemical Oxygen Demand (BOD)	220	20
Chemical Oxygen Demand (COD)	412	120
Total Suspended Solids (TSS)	117	50
Ammoniacal Nitrogen (AN)	34.6	10
Oil and Grease (O&G)	18.7	5

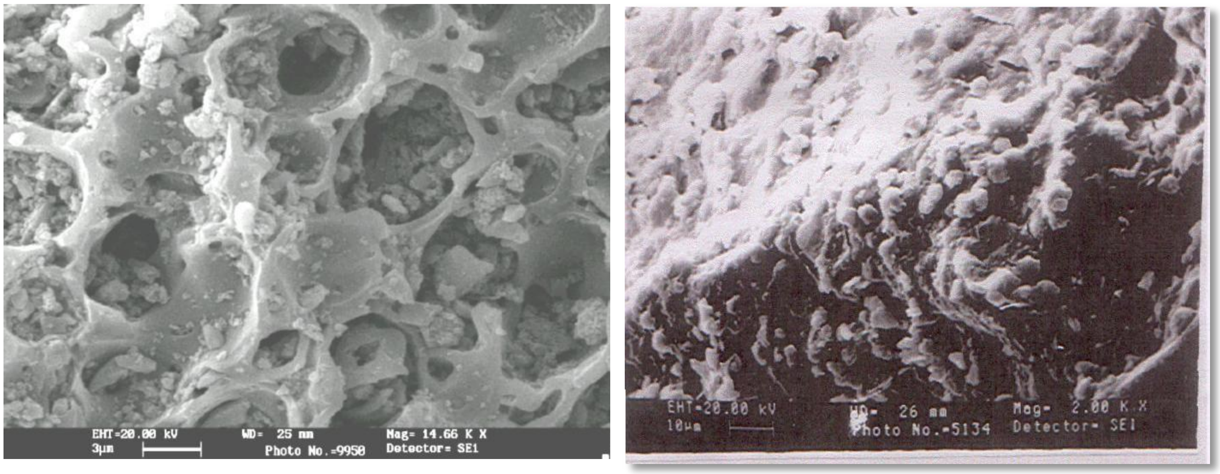
2.2 The Immobilization Media

Activated carbon is well known as a common adsorbent, meaning that it can attach microorganisms or other solutes on its surface and pores. Its good adsorption properties is the reason it is always used as a filter medium for the removal of odour, colour and taste from liquids and gases. Improved type of activated carbon was used in this research where the nano material was used to enhance the surface properties of the activated carbon materials. The activated substrate was taken from the environmental research laboratory of India. The Indian Government's environmental research laboratory has come up with a better form of activated carbon using nano technology. The composition of this activated carbon is given in Table 2.

Table 2: Characteristics of the Activated Carbon Substrate Media

Contents	Concentration
Carbon, C	48.45%
Hydrogen, H	0.70%
Nitrogen, N	0.10%
Ash	50.75%

In terms of physical properties, this activated carbon (Figure 1) has 0.69 g/m^3 of bulk density and 218 m^2/g of specific surface area, much higher than that found for normal activated carbon. This high surface area of the activated carbon was expected to enhance the immobilization of chemotrophs up to about 3.5×10^7 cells/gm.



a) Before Immobilization b) After Immobilization

Figure 1: Image of the Activated Carbon Immobilization Media

2.3 Pilot Plant Setup

The pilot plant set up comprised of 2 sewage holding tanks, 1 anaerobic reactor, 2 Fluidized Immobilized Cell Carbon Oxidation (FICCO) reactors, and 1 AICR. A blower was used to supply oxygen to the cells in the FICCO reactors and AICR. The system operated for 8 hours a day, treating approximately 1000 liters of sewage daily. Raw sewage was pumped up into a holding tank and fed into each tank by gravity. The anaerobic reactor used an upflow anaerobic sludge blanket (UASB) system where the influent was fed through the bottom of the reactor. This stage was absolutely necessary when implementing the AICR technology to reduce the viscosity of wastewater, so that the AICR could perform efficiently. The FICCO reactor on the other hand was a form of fluidized-bed bioreactor with the activated carbon as the support media for the microbes. This stage broke down both chemical and organic contaminants and further reduced the solid concentration in the wastewater. Finally the AICR as packed with 4 layers of different sized aggregates and one layer of activated carbon to treat and filter the incoming wastewater. The carbon acted as a matrix where bacteria were immobilized and provided high cell density. Flow diagram of the pilot plant is given in Figure 2 and a full setup is shown in Figure 3.

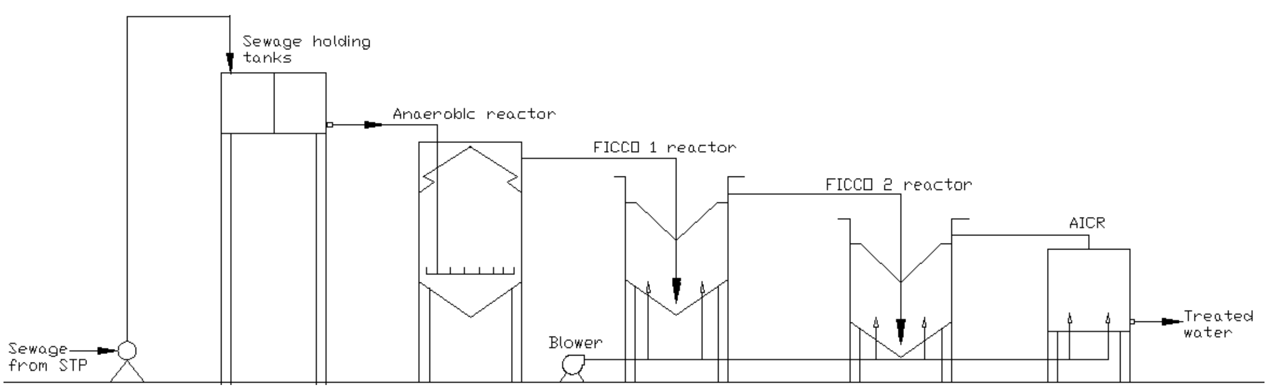


Figure 2: Diagram of the Pilot Plant Process Layout

Figure 3: Image of the Pilot Plant Setup

The raw sewage flowed through the system at an average flow rate of 125 L/hr for 8 hours a day. This equates to approximately 1000 liters of sewage being treated by the system daily. The blower however operates for 23 hours a day with an hour of rest. The capacity for each tank and the retention time is given in Table 3.

Table 3: Capacity and Wastewater Detention Time in Each Tank

Tank	Capacity (L)	Approximate Detention Time (hours)
Anaerobic tank	1120	9
FICCO 1	830	6.5
FICCO 2	830	6.5

2.4 Anaerobic Digestion Tank

This pilot plant used an up-flow anaerobic sludge blanket (UASB) system for the anaerobic digestion of the wastewater. The influent entered bottom of the reactor in an up-flow fashion. The contaminants in the upward flowing wastewater was broken down by the anaerobic bacteria thus improving the quality of the effluent. The resulting biogas was periodically released to the atmosphere through top of the digestion tank (Figure 2).

2.5 Fluidized Immobilized Cell Carbon Oxidation (FICCO) Reactor

The Fluidized Immobilized Cell Carbon Oxidation (FICCO) reactor is classified as a fluidized-bed bioreactor. The operating principle of this reactor is simple; bacteria are immobilized on the surface of the activated carbon which is suspended in water, and oxygen is provided from the bottom of the reactor using a blower. These bacteria break down the unwanted contaminants, while the mixing action produced by the supplied air produce floc which settles in the clarifier.

Some benefits of the FICCO reactor include the reduction of suspended solids to less than 30 mg/l and the removal of odour and color from wastewater. This FICCO reactor performs better compared to the conventional suspended growth and fixed-film waste water treatment processes because of the reactor's high bacterial density. Other benefits of the FICCO reactor include minimum sludge production and low energy cost because the only mechanical equipment required is a blower.

2.6 Advanced Immobilized Cell Reactor (AICR) Technology

The treatment process involved in AICR technology was immobilized cell oxidation process. To be more specific, the activated carbon acted as an insoluble carrier matrix where immobilization of microorganisms occurs in order to prevent the dissipation of oxygen. The main benefit of immobilization is to allow a high cell density to be maintained in a bio-reactor at any flow rate without washing out the required cells. Besides the immobilization of chemo-autotrophs which breaks down chemical contaminants, this reactor allows for the oxidation of dissolved organics in water and also filtration of wastewater.

The AICR used different layers of rocks together with a layer of activated carbon to treat the incoming waste water. The water entering the inlet was distributed onto the carbon layer by a series of pipes with tiny holes (dark blue pipes on top) which helped spread the water over a wider surface area to avoid overloading only one part of the reactor. Oxygen was supplied by a blower to the reactor by a series of pipes (turquoise pipes) embedded into the carbon and rock layers. The AICR was backwashed for 1 hour every day when the blower was switched off to clean the reactor of any deposited solids.

3.0 Results and Discussion

3.1 Start-up of the Plant

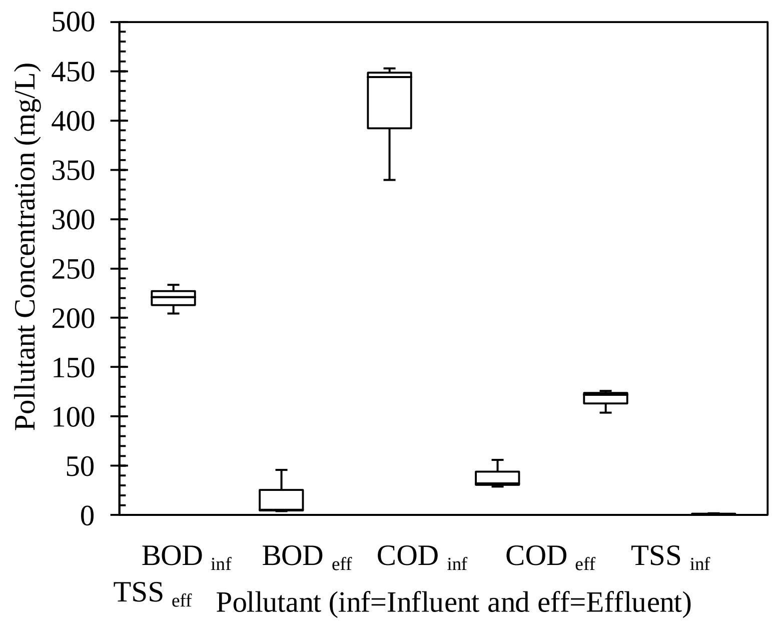
The plant was locally fabricated and installed at the commercial premise close to EcoClean Technology Sdn. Bhd. Then the system was partially filled with active sludge from biological wastewater treatment plants of similar nature. The pilot plant was batch fed with the raw wastewater. The water samples from the influent and effluent locations of the plant were collected and sent to the lab for testing. The pollutant reduction stabilized after 3 months (Table 4), when the start-up period was considered completed. After the start-up period, the BOD concentrations was reduced by 98%, COD by 94% Ammoniacal nitrogen by 90%, oil and grease, and TSS by 99%. These results prove that Class A water quality can be achieved.

Table 4: Pollution Reduction during the Start-up Period

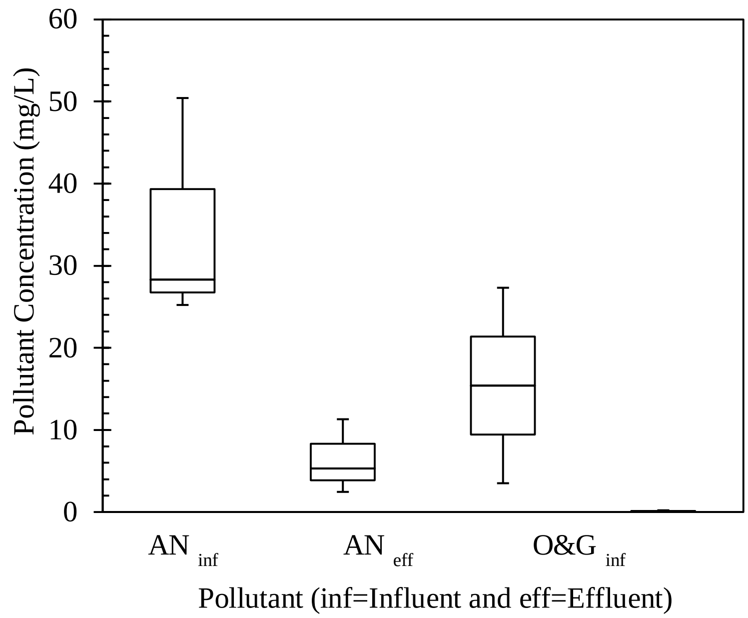
Parameter	Pollutant Reduction (%)	
	After 1 Month	After 3 Months
Biochemical Oxygen Demand (BOD)	78	98
Chemical Oxygen Demand (COD)	84	94
Total Suspended Solids (TSS)	98	99
Ammoniacal Nitrogen (AN)	78	90
Oil and Grease (O&G)	97	99

3.2 Performance of the Treatment Plant

The pilot plant was continued operation and samples were tested to verify the performance of the treatment plant. The pollutants continued to be monitored were BOD, COD, AN, TSS and O&G. Variation of those parameters are shown in Figure 4. The pilot plant continued performing very well showing pollutant reduction more than 90% (Table 5) for most of the pollutants tested in the laboratory. The reduction of TDS was the minimum with a value of 43.7%. This is due to the fact that there was no special unit process to remove the TDS from the water.



a) Variation of BOD, COD and TSS



b) Variation of AN, and O&G

Figure 4: Influent and Effluent Concentrations of the Pollutants during the Start-up Period

Table 5: Pollutant Reduction Performance of at Various Unit Processes

Parameter	Sample from					Reduction (%)
	Influent	Anaerobic	FICCO 1	FICCO 2	Effluent	
pH (Unit)	7.08	6.53	7.50	7.22	7.12	-
Turbidity (NTU)	106	55	14	8	3	97.2
TDS (mg/L)	245	274	209	152	138	43.7
TSS (mg/L)	147	53	21	9	2	98.6
BOD (mg/L)	35	22	7	4	2	94.3
COD (mg/L)	267	198	83	37	6	97.8
AN (mg/L)	23.8	31.0	17.2	11.4	2.1	91.2
O&G (mg/L)	31	7.4	0.3	<0.1	<0.1	99.0

The performance of the pilot plant was also monitored by regularly checking the physical appearance of the water samples from each tank and also by testing the quality of the raw sewage and effluents at various unit processes. A few pictures of the water samples taken at different stages during this pilot test are shown in Figure 5. It can be seen that the treated water quality improved gradually.

Figure 5: Physical comparison of water samples from different locations of the treatment system

(*From Left: Raw Sewage, Anaerobic Tank, FICCO Reactor 1, FICCO Reactor 2 and Treated Effluent from AICR*)

The improved activated carbon used in this AICR technology was capable of operating continuously without altering the efficiency of treatment because of the counter-current movement of liquid and air streams that enables the dissolved organics to undergo oxidation and desorb the converted products. The modified activated carbon can also facilitate selective solute transfer, enhance bio-film attachment or restrict the permeation of microorganisms downstream.

3.3 Advantage of the Technology

Several advantages can be attributed to the operation and performance of the pilot plant system. Less land area is required for the system. Less electrical and mechanical equipment. Less power consumption (about 30% of the conventional consumption). Less treatment time (1- 4 hrs) is required to fulfill the effluent standard required by the legislation. No foaming, bad smell, and other aesthetic problems. No nutrient, settling tank and tertiary treatment is required. Possibilities to reuse the treated effluent for agricultural/recreational purpose. Investment cost is about 75% less than the existing conventional facilities. Payback period of AICR system is 26 months towards savings on electrical power and chemical consumption.

3.4 Disadvantage of the System

A few disadvantages were also identified for the system tested as a pilot plant. Similar to most of the biological treatment plants, the maximum organic loading to the plant is limited. Anaerobic treatment is required before proceeding to AICR reactor. Multiple modules is required to handle huge volumes.

4.0 Conclusions

The Advanced Immobilized Cell Reactor (AICR) technology, presented in this report used improved activated carbon technology patented by the government of India to solve some problems posed by conventional sewage treatment plants (STPs) in Malaysia. High surface area (218 m^2/g) of the actiaved carbon allowed high bacterial density per gram of the immobilization media. This, in turn, enabled the design of small STPs to handle sewage loading comparable to that of conventional STPs. The AICR technology required less energy and mechanical equipment compared to conventional STPs. It used closed system which reduced odour, and can be scaled to any size to meet specific requirements. The setup time for this pilot plant was very short and it took about 3 months to complete the start-up period and to deliver satisfactory performance. This results of the pilot plant indicated that this technology is indeed capable of treating wastewater to produce high quality effluents. There is also a potential to reuse the effluent with some additional treatment depending on the usage and desired quality of recycled water. One of the main benefits of this technology is the modular nature of the system, where many small reactors can be used together for treatment instead of one big reactor. Such modules can also be added to the existing treatment plants to handle the increased load due to increased population serving the sewerage catchment.

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