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Start-up of Modified Anaerobic Baffled Reactor for the Treatment of Landfill Leachate by Using Granular Sludge

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Abstract

The objective of this study was to valuate the start-up performance of the Modified Anaerobic Baffled Reactor (MABR) system by using granular sludge treating landfill leachate. Anaerobic reactor start-up is a complex process as it depends on the substrate characteristics, working conditions, inoculum and reactor configuration. To reduce the start-up time and have better operational parameters control in anaerobic processes, important factors are needed to enhance the high-rate anaerobic systems efficiency. Sludge granulation was indeed an achievement in anaerobic wastewater treatment technology and has greatly enhanced its efficiency and applicability. It holds many advantages, such as mutual defence against antagonists, efficient reactor operation without sludge washout, and effluent with low suspended solids. Granules are the functional units which comprise different microorganisms that are required for the methanogenic degradation of organic matter. Results from this study showed a successful start-up of the MABR system at an organic loading rate (OLR) of 0.0875 kgCOD/m^3/d and hydraulic retention time (HRT) of four days. During this period the Chemical Oxygen Demand (COD) removal efficiency was 99 % and the gas production increased steadily from 0.013 L/d to 0.021 L/d.

Keyword: Landfill leachate, Modified anaerobic baffled reactor (MABR), Granular sludge, Meat extract

1 Introduction

Out of the problems which are generally encountered in the anaerobic treatment of wastewater, one of the problems is related to the complication in start-up. This was discussed in previous studies that a considerable amount of time was required in the start-up of anaerobic systems [1]. The main issue of concern is the development of microbial culture which is suitable the most to the incoming wastewater, vulnerable nature of most anaerobic bacteria and utmost oxygen liability of the enzyme systems of obligate anaerobes renders the reactor population more susceptible to slight fluctuations [1].

While initialising the start-up of anaerobic reactor, the biomass in the reactor system is to get acclimatised with the type and strength of wastewater(substrate),operating parameters in the reactor system and the configuration of the reactor.Additionally, fast growing acidogens outnumber methanogens and certain acetogen [2,4]. As a result, volatile acids (VA) and dissolved H_2 are accumulated. Generally, anaerobic reactors are commenced on mesophilic temperature (33°C –40°C) and it advances the growth of methanogens. The temperature maintained during the treatment of landfill leachate by using Modified Anaerobic Baffled Reactor (MABR) in this study was 35°C –40°C. Shorter start-up times can be made by using wastewater that is low in particulate organics. When the organic loading rate (OLR) and Chemical Oxygen Demand (COD) concentrations are reduced by 80% ,then the value of OLR should be increased[5]. If the time of start-up of anaerobic reactors is reduced and the operational parameters of the system are optimum, then it will contribute to the increase in the efficiency of the anaerobic system [6]. The objective of this study is to identify and evaluate the start-up performance of the MABR by using synthetic wastewater (meat extract).

Sludge granulation is indeed an achievement in anaerobic wastewater treatment technology as granular sludge has many advantages as compared to sewage sludge. Biomass retention is possible inside the reactor without the supply of a carrier material, thereby improving the economics of the process. Anaerobic granules are basically the particulate biofilms, formed impulsively by auto immobilisation of anaerobic bacteria in the absence of a support media. These dense particles, consisting of an entwined mixture of the collegial anaerobic micro-organisms that work together in methane fermentation, are the driving force

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for the successful operation of the modern, high-rate anaerobic digester [7].

The granules are the functional units which comprise different microorganisms required for the methanogenic degradation of organic matter. A granule may contain millions of organisms in a single gram of biomass. The unique spatial arrangement of bacteria within an anaerobic granule and the phenomenon of granulation offers many advantages: 1. Mutual defence against antagonists; 2. Efficient reactor operation without sludge washout; 3. Effluent with low suspended solids.Granular sludge-based bioreactor technologies are recognised worldwide as cost-effective and efficient for the anaerobic treatment of industrial and municipal wastewater [8].

2 Materials and Methods

2.1 Modified Anaerobic Baffled Reactor (MABR)

Wastewater treatment emphasises on achieving these requirements: a) Uncomplicated design, b) minimal construction and maintenance cost, and c) high efficiency in treatment. Anaerobic technology is favoured over aerobic technology because anaerobic processes consume less energy and produce less sludge, which directs to lower operational costs as compared to aerobic processes.

ABR, which is a high-rate anaerobic reactor can be regarded as one of the most efficient anaerobic treatment systems. ABR can treat industrial wastewater, such as textile, pharmaceutical, petrochemical, paper mill and others, respectively, which usually contains recalcitrant (non-biodegradable) compounds. The MABR is a laboratory scale plexiglass reactor which has 28 L capacity and contains four uniform compartments (7 L capacities) and each has a slanted baffle (45°), heater (to maintain the temperature within mesophilic range) and sludge and gas sampling ports (Figure 1). The length, width and height of the reactor is 82, 17 and 32 cm, respectively. The MABR is an enhancement of the conventional ABR, whereby each compartment is further supplemented by slanted baffles to encourage mixing within the compartment and control sludge washout. The MABR was designed and developed by [9]. A synthetic wastewater (glucose) is used to start-up and evaluate its reactor performances.

In this study, meat extract was used to investigate the performance of the MABR during the start-up, which was achieved by low OLR of 0.0875 kg COD/m^3/d and hydraulic retention time (HRT) of 4 days, so that the substrate will acclimatise with the anaerobic granular sludge, resulting in efficient start-up of the MABR system. Gas production was monitored on individual basis for each compartment by using Tedlar bags of 1-litre capacity and bubble counters. It is cardinal for an effective operation to control temperature since microbe activity drops off extensively as temperature falls [10]. A timer was applied for 15 min per hour to keep the uniformity of temperature and avoid overheating of the compartments. Peristaltic pumps were used to check and regulate the flow rate for the influent.

2.2 Nutrients

Macronutrients N100 were used to overcome nutrient deficiencies. Alkalinity of the feed was adjusted to 1000 mg/l – 2000 mg/l by adding $NaHCO_3$ to the feed whenever it was needed.

2.3 Synthetic Wastewater

The synthetic wastewater consists of protein and other added chemicals which is readily degradable. It produces actively considerable intermediary metabolites in the anaerobic degradation and was used as a carbonaceous substrate in past research. Table 2 shows the characteristics of meat extract used as synthetic wastewater.

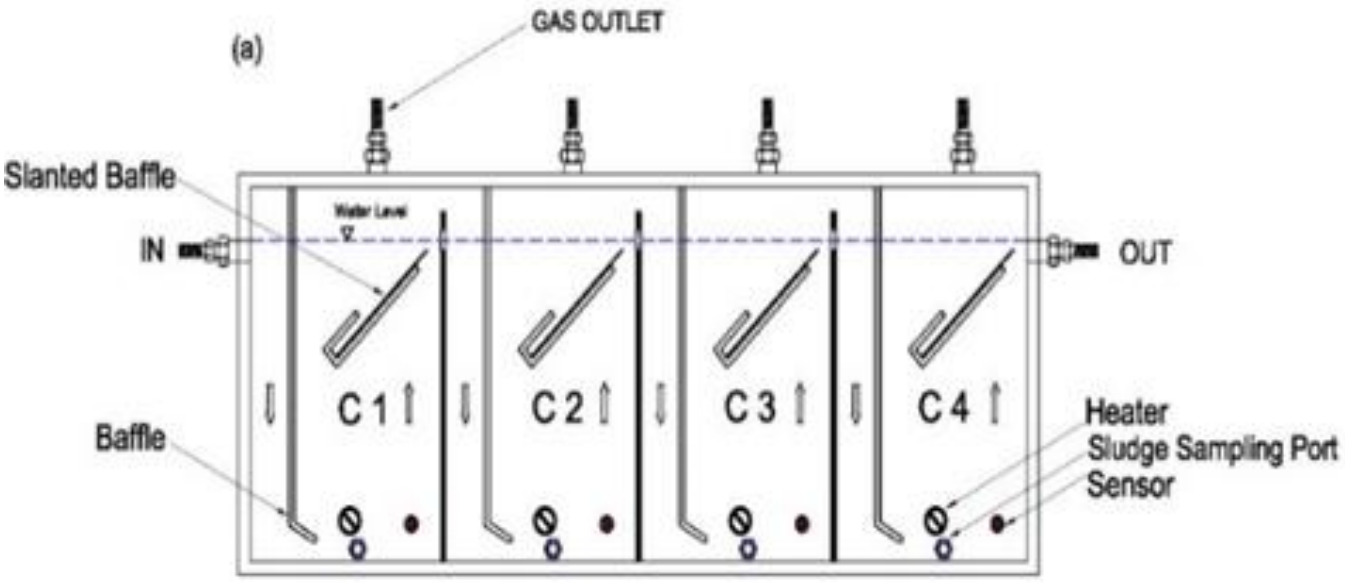

Figure 1: Schematic diagram showing modified anaerobic baffled reactor (MABR)

Table 1: Characteristics of the N100

Nutrients	Composition	Nutrients	Composition
Crude fat (min)	2%	Riboflavin	8.00 mg
Crude fibre (max)	8%	Selenium	0.00002%
Crude protein (min)	5%	Manganese	0.09%
Nitrogen free extract	45%	Zinc	0.005%
Boron	0.018%	Folic Acid	0.30 mg
Calcium	2%	Vitamin A	50,000 IU
Cobalt	0.0008%	Niacin	25.00 mg
Copper	0.0005%	Pantothenic Acid	0.20 mg
Fluorine	0.015%	Thiamine	3.00 mg
Iodine	0.03%	Choline	50.00 mg
Iron	0.08%	Biotin	0.30 mg
Magnesium	0.50%	Vitamin E	150 IU
Potassium	2%	Vitamin B12	0.04 mg
Salt	2%	Ascorbic Acid	1500.00 mg
Sulphur	2%	Vitamin K	1.00 mg

Table 2: Ingredients of meat extract used as synthetic wastewater

Ingredients of meat extract	Weight per 100 g
Energy	983 kJ
Calories	231 kcal
Protein	38.4 g
Carbohydrates	19.2 g
Fat	0.1 g
Fibre	3.1 g
Sodium	4.3 g
salt	11 g
Thiamin	5.8 mg
Riboflavin	7.0 mg
Niacin	160.0 mg
Folic acid	2500 µg
Vitamin B12	15.0 µg

2.4 Granular Sludge

Seed sludge which was used in MABR system for the start-up was obtained from an anaerobic digester treating food waste.The sludge is a naturally occurring biocatalyst having its wide application as inoculation material for the start-up of bioreactors for the anaerobic treatment of wastewater. Table 3 shows the properties of the granular sludge.

2.5 Sampling and analysis

Sample analysis, such as COD and pH were conducted according to standard methods [11] by using DR 6000 spectrophotometer. The total biogas volume was determined by using an optical gas bubble counter.

Table 3: Properties of granular sludge

Aggregation	Thick fluid (sediment solids)
Odour	Light aroma of rotten eggs
Colour	Grey-black
Solubility	Pellet-like particles
Density (kg/l)	1.0 to 1.1
Acidity (pH)	7 to 9
Reactivity	Stable at ambient temperatures and under normal conditions of usage.
Chemical Stability	The product is quite stable

3 Results and Discussions

3.1 pH

The groups of microorganisms which are viable for the anaerobic degradation have a defined range for their most favourable growth, and values outside this range can cause adverse impact to the process, especially methanogens.Therefore, stable pH value within the digester should be one of the priorities in ensuring efficient methanogenic digestion. The start-up of the MABR lasted for 28 days. During the start-up, a determined concentration of feed COD (350 mg/L) was kept until a steady state COD removal and pH value were achieved, respectively. The OLR and HRT were also maintained at 0.0875 kgCOD/m^3/d and four days, respectively. Figure 2a illustrates the pH profile during start-up period. The pH levels during reactor start-up by using the synthetic wastewater were generally stable (pH 7.0 – pH 8.1) in all compartments of the MABR until Day 12, whereby a slight reduction (pH 6.3 – pH 6.7) was observed in all compartments from Day 16–Day 20, of the MABR, but it recovered to stable conditions on Day 28. For anaerobic digestion, the alkaline phase is preferred to maintain stable microbial populations in the sludge. Many anaerobic reactors fail to operate at low pH (less than 6.7). It is important to maintain a suitable alkalinity in the reactor. Also, in literature many anaerobic reactors were operated in the alkaline region [12]. The variations in pH were caused by biochemical processes (acidogenesis and methanogenesis) which were taking place in the same reactor. Conversion of reactant to substrate by the anaerobic bacteria, which was not stable during the anaerobic digestion, caused the fluctuation of pH. However, the behaviour from 20–28 days, showed that the pH values were stabilising.

3.2 COD

The COD removal efficiency during start-up showed a steady increase from Day 1 up to Day 28 (Figure 2b). The MABR was started at an OLR of 0.0875 kgCOD/m^3/d and long retention time (four days), Solids will be accumulated in the reactor with increased methanogenic populations and resilience to hydraulic shock load ``[13]. The COD removal efficiency, increased at a steady rate from 58% to 99%, affirming that the reactor start-up was efficient. Regardless of low pH levels were noticed during the initial operational period (until Day 12), the removal rate of COD was still high, showing that the performance was not affected by the fluctuation of pH.

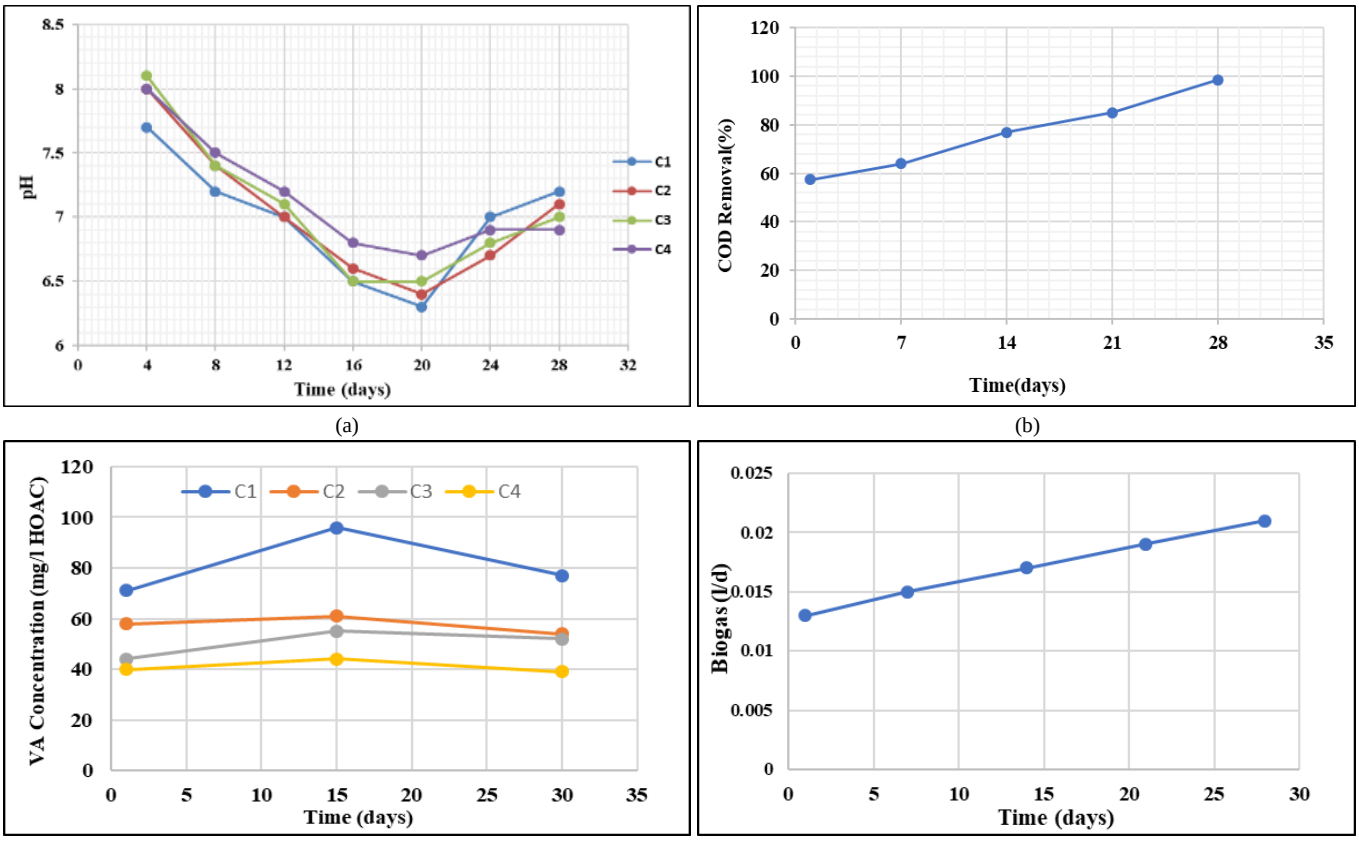

Figure 2: (a) pH profile during start-up of MABR (b) COD removal during start-up of MABR (c) VA profile during start-up of MABR (d) Biogas production during start-up MABR

3.3 VA

VA is a useful indicator to evaluate the anaerobic reactor performance. The more VA is being utilised inside the reactor, the better the reactor operation. According to [14] VA of less than 150 mg/L in an anaerobic reactor, indicated that the reactor was operating under stable conditions. In general, if the pH of the reactor system is high (e.g. pH 7 – pH 7.5), the VA should be lower [15], and in the current study, this trend was clearly observed (Figure 2c). The VA concentration in all compartments during reactor start-up by using the synthetic wastewater was stable throughout the study (40 mg/L – 95 mg/L HOAC), confirming a stable operation of the reactor. In the current study, acetic acid was evaluated for the acid concentration in the reactor due to its main desire for methanogenic digestion. Low VA concentration was observed in C4 (around 40 mg/L HOAC) throughout the start-up.

3.4 Biogas

The anaerobic microorganisms cause breakdown of the organic waste in a digester in the absence of oxygen to give biogas. The degradation of organic matter is a consequence of the operation of two important groups of microorganisms. Firstly, the acid forming bacteria which break down complex organic compounds (proteins, fats and carbohydrates) into simpler ones like volatile fatty acids, lower alcohols, hydrogen, carbon monoxide, acetic and formic acids. Secondly, these become the food for the other group which further change it into desired methane and carbon dioxide [16, 17]. The environmental advantage of biogas is that it is sustainable alternative to fossil fuels. It reduces Green House Gases (GHG) emissions; hence, it is an ecofriendly gas. Figure 2d shows the total gas production during reactor start-up. It can be seen that the gas output increased steadily from 0.013 L/d to 0.021 L/d during the functional period, confirming that the degradation of the substrate was taking office.

4 Conclusion

The performance of MABR during rector start-up by using granular sludge showed successful treatment of a promising method for wastewater treatment (performance treating synthetic wastewater). The MABR showed a successful start-up at an OLR and HRT of 0.0875 kgCOD/m^3/d and four days, respectively, by using the synthetic wastewater (meat extract). A COD removal efficiency of 98.5% was observed during this period.

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Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analysis and manuscript writing.

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