Experimentation on the anaerobic filter reactor for biogas production using rural domestic wastewater

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Abstract— The biogas production from anaerobic filter (AF) reactor was experimented in Taihu Lake Environmental Engineering Research Center of Southeast University, Wuxi, China. Two rounds of experimental operations were conducted in a laboratory scale at different Hydraulic Retention Time (HRT) and wastewater temperature. The biogas production rate during the experimentation was in the range of 4.63 to 11.78 L/d. In the first experimentation, the average gas production rate was 10.08 L/d, and in the second experimentation, the average gas production rate was 4.97 L/d. The experimentation observed the favorable Hydraulic Retention Time and wastewater temperature in AF was three days and 30.95°C which produced the gas concentration of 11.78 L/d. The HRT and wastewater temperature affected the efficiency of the AF process on the organic matter removal and nutrients removal as well. It can be deduced from the obtained results that HRT and wastewater temperature directly affects the efficiency of the AF reactor in biogas production. In conclusion, anaerobic filter treatment of organic matter substrates from the rural domestic wastewater increases the efficiency of the AF reactor on biogas production and gives a number of benefits for the management of organic wastes as well as reduction in water pollution. Hence, the operation of the AF reactor in rural domestic wastewater treatment can play an important element for corporate economy of the biogas plant, socio-economic aspects and in the development of effective and feasible concepts for wastewater management, especially for people in rural low-income areas.

1. Introduction
Exponential growth in population, urbanization, improved socio-economic standard of living and advances in technology have caused an extraordinary increase in the demand for quality water and energy. As demand for quality water increases, the volume of wastewater generated increases [1, 2].

Rural domestic wastewater generally contains high concentrations of nutrients and organic matter as well as other toxic and pollutants including pathogenic micro-organism which if not properly treated will results into lakes eutrophication and pollution of water environment. Hence, the major objective of rural domestic wastewater treatment by anaerobic filter (AF) is to protect the water environment that has significant effect on the survival and development of the rural communities [3].

Furthermore, anaerobic filter reactor is suitable for biogas production and greenhouse gas (GHG) emissions reduction and has been identified as an established and less cost process for treatment of rural domestic wastewater.
The anaerobic filter (AF) process has gained popularity and has been applied in various rural domestic wastewater treatment schemes since it was first developed by Young and McCarty (1969). It is predominantly a column filled with filtering media for the development of biofilms.

Several studies have been conducted to evaluate the efficiency of AF reactors [4, 5] in treating rural domestic or low-strength wastewater. In other studies experimented in anaerobic co-digestion reactor, the effect of hydraulic retention time (HRT) on biogas production was examined by [6]. Important parameters affecting the performance of the AF reactor are the operating HRT and temperature [7]. When the temperature is high, the conversion rates of organic matter in the anaerobic process are also high and at the same time, low temperature leads to low gas production in upflow reactors and insufficient mixing. When the sewage temperature is low, more organic matter usually remains un-degraded as a result of slow hydrolysis of volatile solids at a given HRT [8]. Other studies show that, at low temperatures, longer HRTs are needed because of the lower rate of hydrolysis in AF reactors [9].

2. Material and Methods

2.1 Experimental raw materials and setup

This experimental study used the low strength rural domestic wastewater. The influent was obtained from the wastewater manhole at the Taihu Lake Environmental Engineering Research Center of Southeast University, Wuxi, China, and then pumped into a storage tank as influent to the AF reactor. The inoculants of the AF reactors collected from Wuxi wastewater treatment plant located in Wuxi urban area, Jiangsu Province, China. The AF reactor system was composed of three columns made of polyvinyl chloride (PVC) and a total capacity of 300 litres. All the three AF columns were characteristically run as an anaerobic zone. The first two columns aimed mainly at the removal of wastewater solids so as to offer high quality processing environment for the performance of the third column. Usually, in the second and third columns optimization of volatile fatty acid (VFA) removal takes place [10]. The AF reactors were connected in a series. The three anaerobic columns had an internal width of 20 cm and a height of 300 cm. The columns was filled with filter material of non-woven fabric with a length of 25 cm, width of 0.5 cm, surface area of 150 m²/m³, and with a porosity of 97%. The effective volume of the AF reactors was 90 liters for each anaerobic column. Samples for laboratory tests were obtained from the influent tank and AF reactors’ sampling points (Fig. 1) at three (3) days interval and preserved in a refrigerator at 5°C. Values of pH, temperature, and gas production rate were recorded daily. The average composition of the raw rural domestic wastewater experimented is illustrated in Table 1.

![Figure 1. photo of AF reactor](image)
Table 1. Average composition of the studied raw domestic wastewater

| Item     | COD concentration (mg/l) | TN concentration (mg/l) | TP concentration (mg/l) | pH value |
|----------|--------------------------|-------------------------|-------------------------|----------|
| Minimum  | 76.0                     | 19.45                   | 1.3                     | 7.3      |
| Maximum  | 385.6                    | 40.26                   | 4.31                    | 7.9      |
| Average  | 200.3                    | 33.02                   | 3.26                    | 7.6      |

The flow rates were 300 L/d, 150 L/d, 100 L/d, and 75 L/d corresponding to HRTs of one day, two days, three days and four days, respectively. The first six months of the experimental operation were conducted with HRTs of one, two, and three days and run at mesophilic conditions (high temperature operations).

After assessing the response of the reactor performance to those experimental factors and conditions in the first round of operations (mesophilic operations), the reactor was then operated with HRTs of four days and operated at psychrophilic conditions (low temperature operations).

2.2 Removal Efficiency of AF Reactor
The COD removal in the AF reactor is calculated as the difference between the influent concentration ($C_{inf}$) of COD and the effluent concentration ($C_{eff}$) of COD. Thus, the removal rate ($R_e$) of COD is expressed by the following equation:

$$ R_e = \frac{C_{inf} - C_{eff}}{C_{inf}} \times 100\% $$

3. Results and Discussion

3.1 COD Removal
The average concentrations of COD in the influent and effluent of the AF system were, in the first experimentation was, 254.1 mg/L and 60.5 mg/L and in the second experimentation was, 184.8 mg/L and 76.7 mg/L, respectively (Table 2 & table 3).

Table 2. Influent and effluent COD concentrations and removal efficiencies in first experimentation

| Month     | Temperature °C | HRT (d) | OLR for COD (kg/(m³·d)) | $C_{inf}$ (mg/L) | $C_{eff}$ (mg/L) | Removal efficiency (%) |
|-----------|----------------|---------|--------------------------|------------------|------------------|------------------------|
| April     | 27.08          | 1       | 0.23                     | 231.47           | 81.71            | 64                     |
| May       | 28.57          | 1       | 0.23                     | 229.16           | 73.11            | 68                     |
| June      | 28.34          | 2       | 0.12                     | 237.68           | 66.04            | 72                     |
| July      | 29.67          | 2       | 0.12                     | 243.05           | 54.00            | 78                     |
| August    | 30.91          | 3       | 0.09                     | 290.19           | 38.01            | 87                     |
| September | 30.95          | 3       | 0.09                     | 293.13           | 30.26            | 90                     |
The COD removal efficiency throughout the treatment process in the first experimentation was between 64% to 90% under the conditions of HRTs of one day, two days, and three days; OLRs for COD of 0.09 to 0.23 kg/(m³·d); temperatures ranging from 27.08 °C to 30.95 °C respectively.

The experimental results showed that HRT, temperature and OLR have a significant influence on COD removal. In the first experimentation, reducing HRTs from three to two days, and then to one day increases OLR and thus affects the efficiency, resulting in average COD removal rates of 88.5%, 75%, and 66%, respectively. This indicates that COD removal efficiency became less efficient and more variable with the HRT reduction, and this was found to be independent of the influent concentrations. A low HRT caused pre-acidification, resulting in accumulation of COD (as VFA), which did not subsequently convert to methane, resulting in an accumulation of VFA. This result agrees with the trend observed by [11], who showed that little change occurred in COD removal efficiency when an ABR was operated at constant OLR (4.8 kg COD·m⁻³·d⁻¹) with decreasing HRT (20 - 6.6 h). They concluded that, at low OLRs, there is enough biomass to metabolise the feed, and, even when the substrate concentration decreases with decreasing HRT, the mass transfer into the flocs is sufficient to remove most of the substrate. In spite of the highest organic loading rates (OLR) - (kg/(m³·d)) HRT of one day, COD removal efficiencies increased on average 64 % (temperature of 27.1 °C) to 68% (temperature of 28.6 °C). Therefore, 64–68 % COD removal can be achieved at HRT of one day at temperatures of 27.1 – 28.6 °C.

In the second experimentation, an increase in HRT and temperature led to improved efficiency of the reactor, in the range from 53% to 63% (Table 3). The maximum COD removal rate was 63%, which corresponds to an influent COD of 198.27 mg/L at a HRT of four days and temperature of 18.53%. The removal efficiency obtained coincided with the study conducted by [12], which achieved a COD removal efficiency of 74% when treating municipal wastewater at temperatures between 18 °C and 28 °C. Comparison of the two rounds of experimentation showed that the COD removal efficiency of the anaerobic reactor increased with an increase in HRT and temperature, and decreased with an increase in OLR. This agreed with the findings of [13], who reported a COD removal rate of 65% at high temperatures in a UASB reactor, which decreased to a removal rate of 55% when the temperature was reduced to between 13 °C and 17 °C. Also other studies revealed the performance of an upflow anaerobic treating domestic wastewater, obtaining organic matter removal efficiency between 46 - 90 % when the temperature has increased.

### 3.2 Gas Production Rate
The average gas production rate varying with time is shown in Tables 4 and 5. As the system stabilized, the average gas production rate varied between 5.82 and 8.39 L/d in the first experimentation (Table 4) and in the range of 6.01 to 8.36 L/d in the second experimentation (Table 5).
Table 4. Gas production rate in first round of experimental operations

| Month     | Temperature (°C) | HRT (d) | Gas production rate in different anaerobic columns (L/d) | Total gas production rate (L/d) |
|-----------|------------------|---------|--------------------------------------------------------|--------------------------------|
| April     | 27.08            | 1       | 2.53, 4.64, 3.75                                       | 10.92                          |
| May       | 28.57            | 1       | 2.16, 3.51, 2.21                                       | 7.88                           |
| June      | 28.34            | 2       | 3.53, 4.07, 1.44                                       | 9.04                           |
| July      | 29.67            | 2       | 3.26, 5.19, 3.28                                       | 11.73                          |
| August    | 30.91            | 3       | 3.18, 5.36, 3.24                                       | 11.78                          |
| September | 30.95            | 3       | 2.66, 3.62, 2.82                                       | 9.10                           |

Table 5. Gas production rate in second round of experimental operations

| Month      | Temperature (°C) | HRT (d) | Gas production rate in different anaerobic columns (L/d) | Total gas production rate (L/d) |
|------------|------------------|---------|--------------------------------------------------------|--------------------------------|
| October    | 30.67            | 4       | 1.83, 2.16, 1.32                                       | 5.31                           |
| November   | 30.57            | 3       | 1.14, 2.06, 1.43                                       | 4.63                           |

The gas production rate during the experimentation was in the range of 4.63 to 11.78 L/d. In the first experimentation, the average gas production rate was 10.08 L/d, and in the second experimentation, the average gas production rate was 4.97 L/d. For the first experimentation, the highest gas production rate was 11.78 L/d in August, and the lowest was 7.88 L/d in May. The highest amount recorded was due to an increased HRT and also due to the fact that August was the hottest season with high temperature records. This indicates that, the higher the temperature, the higher the gas production from AF reactor. Moreover, in May, the average gas production rate dropped significantly to 7.88 L/d. This may have been a result of a decreased HRT, where biomass has a higher propensity to be washed out from the AF system. A study by [15] experienced a decline in the gas production rate when the temperature was low which revealed a 78% decrease in the gas production rate when the temperature was reduced from 30 °C to 10 °C. Generally, the average gas production rate decreased in the second experimentation as a result of low temperature.

Gas production in each column differed, with column 1 generally producing less gas than the other column. The average gas production showed a relatively constant profile and was largely unaffected by HRT in all the columns throughout the experimentation period, with column 1 having 2.9 L/d; column 2, 4.41 L/d and column 3, 2.79 L/d in the first experimentation period and column 1 having 1.49 L/d; column 2, 2.11 L/d and column 3, 1.38 L/d respectively during the second experimentation period. The lower values gas production, particularly in column 1, were most likely caused by solids accumulation in the early stages, which were higher than in the later stages of the AF reactor.
4 Conclusion
In this study, the effect of HRT and temperature on biogas production from rural domestic wastewater by anaerobic filter reactor was assessed. In this experimentation, the study found that the suitable HRT and temperature that yielded the average maximum gas production rate of 11.78 L/d was at 3 days and temperature of 30.91°C. In conclusion, anaerobic filter (AF) treatment of various biomass substrates from the rural domestic wastewater increases the efficiency of the reactor on biogas production and gives a number of benefits for the management of organic wastes as well as reduction in water pollution.

Hence, the operation of the AF reactor in rural domestic wastewater treatment can play an important element for corporate economy of the biogas plant, socio-economic aspects and in the development of effective and feasible concepts for wastewater management, especially for people in rural low-income areas.

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