Abstract

The laboratory type of the conventional completely mixed anaerobic reactor (CMAR) is a 20 *l* glass bottle with a stirrer coming in through the neck. The CMAR was maintained in a waterbath at 37^{o}C. Two CMARs were operated, namely, the Test reactor and the Control reactor. All the tests for the CMAR where carried out in the Test reactor and the Control reactor was maintained at steady state. A second type of reactor, anaerobic baffled reactor (ABR) was also operated. The ABR is a rectangular perspex box with internal vertical baffles alternately hanging and standing. The baffles divide the reactor into eight different compartments with a total working volume of 7.5 *l*. The upflow chamber in each compartment is twice the width of the downfow chamber. Each baffle is angled at about 45^{o} to distribute the flow towards the centre of the upcomer. The ABR was set up in a controlled temperature room. The critical difference between the CMAR and the ABR is that the CMAR is essentially a mechanically stirred reactor whereas the ABR is an upflow hybrid reactor.

A batch of raw sewage from Umbilo sewage works (Durban, South Africa) was used in the reactors for experiments to compare the start-up of the CMARs and the ABR. The two CMARs were operated first whilst the ABR was started up later since it has a shorter HRT. Although the CMARs had been in operation for a long time they did not achieve steady state because the acid solution used to measure their gas production through displacement entered the reactors resulting in a decrease in pH. The pH decreased to values of about 6.3 which is out of the optimum range of 6.5 to 7.8 for methanogens (Haandel and Lettinga, 1994). This accidental influx of acid occurred up to day 32. The Test reactor had calcium hydroxide added to it to enable it to recover from acid contamination. The Control reactor was left to recover without any chemical additions. The HRT was reduced to 37 d from 20 d so as to reduce the amount of volatile acids in the reactors. Eventually the CMARs were fed with the sucrose feed to enable comparison with the ABR and also to increase stability of the reactor contents. They finally achieved steady state at an organic loading rate (OLR) of 0.2 kg/m^3.d. The ABR was first sparged with nitrogen and then the reactor was inoculated with ca. 7.5 *l* of the raw sewage with the outlet sealed to prevent air contamination. A litre of sucrose feed was then added and the reactor left to for 3 days to stabilise and allow the biomass to settle. Feeding began at a HRT of 60 h. This gave a volumetric organic load of 1.6 kg/m^3.d. After the reactor achieved steady state at this volumetric organic load the HRT was reduced to 35.7 h (2.7 kg/m^3.d). There was an increase in gas production as a result of the increased organic load. The HRT was then reduced to 20 h (4.8 kg/m^3.d) and was maintained at this loading rate until the reactor reached steady state. The experiments maintained an initially long retention time (60 h), which was reduced, in a stepwise fashion during which time substrate concentration was kept constant. This provided better reactor stability and superior performance than a reactor with a constant and low retention time coupled with a stepwise increase in substrate concentration.

The operational parameters monitored were the pH, total solids, volatile solids, alkalinity and gas production. At a later stage gas composition and COD measurements were also taken. During the start up period for the Test reactor a total of ca. 14.99 g (calcium hydroxide) were added to correct the pH. The pH eventually stabilised at about 7.15. The Control reactor had a steady increase in pH to the same value. This demonstrated the ability of anaerobic reactors to recover from upset without chemical additives. The ABR had a pH higher than 7 at all times. This was mainly due to a sample collection error. The Ripley Ratio (RR) for the CMARs was initially below 0.3, which is the maximum value for an efficiently operating water treatment system. However, due to the acid contamination they increased to values of about 0.5. This was eventually corrected to values below 0.3 due to the reduced loading rates. The TS of the CMARs showed a downward trend from a value of about 3.2 gTS/*l* to 1 gTS/*l*. This decrease in total solids was due to the change in feed fromraw sewage to the synthetic sucrose feed, which had a lower TS content. There was a gradual increase in the TS of the ABR as the poor settling biomass was removed. It eventually leveled of at about 4 gTS/*l*. The VS of the CMARs were reduced from about 2 gVS/*l* to about 0.5 gVS/*l*. The CMARs had a decrease in gas production due to acid contamination. This was followed by erratic gas production, as the conditions in the reactors had not stabilised. The gas production finally stabilised to about 2500 m*l*/day. The ABR operated for some time without any gas production. When gas production began there was a gradual increase in gas production to average at about 2000 m*l*/day at the initial loading rate. Each increase in the loading rate brought about a sudden anomalous increase in gas production due to the increased mixing.

The research by many scientists has shown that Monod's equation or some variant of it can describe the breakdown of many organic compounds by the bacteria in the different anaerobic processes. In sewage treatment, however, the micro-organism are in a suspended solid mass. In this mass inorganic and inert biological organic matter are intermingled with the different types of anaerobic bacteria. This makes it feasibly difficult to determine the bacterial concentration experimentally. This also makes it difficult to measure the concentration of the different groups of active bacteria in an anaerobic biomass. The biodegradable matter cannot be distinguished from the non-biodegradable mass making it difficult to quantity its exact mass. Furthermore, the concentration of substrate at the surface of the bacteria differs from that in the bulk of the liquid phase due to absorption. As a result the concentration of the bulk liquid phase of the reactor or the effluent is not indicative of availability of substrate to the micro-organism in the treatment system. Thus the empirical approach of evaluating the observed experimental results is the only alternative for design and optimisation of anaerobic digestion systems. In the design of an anaerobic reactor, the maximum organic load it can withstand is related to the biomass retention capacity of the reactor. The biomass retention capacity is a factor dependent on the retention time of the sewage in the reactor.

The organic loading tests were undertaken with a stepwise increase in the influent substrate concentration. The feeding commenced at an OLR of 4.8 kg/m^3.d for the ABR. The OLR was doubled when the reactor reached steady state. The flow rate (HRT) into both reactors and other parameters were kept constant. The substrate concentration was increased from 4 gCOD/*l* (4.8 kg/m^3.d) to 64 gCOD/*l* (76.8 kg/m^3.d) for the ABR. For the CMAR it was increased from 4 gCOD/*l* (0.25 kg/m^3.d) to 32 gCOD/*l* (2 kg/m^3.d). The method used was to increase the organic loading rate until the reactors failed. Since the two reactors had different operating HRTs, the tests began when both had the same COD removal rate of about 60 % COD reduction. The same parameters as in the start-up period were monitored for both reactors. Prior to reactor failure the pH for the ABR fluctuated but was always above 7.3 while the pH in the CMAR was constant at 7.5. The CMAR was able to produce a maximum of 4000 m*l*/day of biogas at an organic loading rate of 0.5 kg/m^3.d. The ABR produced ca. 15000 m*l*/day of biogas at an organic loading rate of 38.5 kg/m^3.d. Both reactors showed an increase in gas production with an increase in the loading rate. Thus the acclimated biomass in the reactors was shown to have increased activity with an increase in organic loading rate. The biogas produced at steady state contained 10 to 15 % nitrogen, 50 to 62 % methane and 25 to 30 % carbon dioxide. The CMAR had a COD removal efficiency ca. 70 %, which did not fluctuate when OLR was increased. The ABR reached a maximum COD removal of 80 %. An increase in the OLR led to an initial decrease in the COD removal until the biomass recovered and the high COD (80 %) removal rates resumed. The ABR reached a maximum OLR of 76.8 kg/m^3.d whilst the CMAR reached a maximum OLR of 2.0 kg/m^3.d. The investigations showed that the ABR could be operated at higher organic loads than the CMAR and give the same organic removal rate. This verified the importance of increasing the SRT/HRT ratio in anaerobic reactors. The CMAR, however, proved to be stable to changes in the influent feed strength, as there was no immediate noticeable changes in the gas production.