Cavitation for improved sludge conversion into biogas

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Abstract.
In several studies the beneficial influence of pre-treatment of waste activated sludge with cavitation on the biogas production was demonstrated. It is however, still not fully certain whether this effect should be mainly contributed to an increase in conversion rate of organics into biogas by anaerobic bacteria, and how much cavitation increases the total biogas yield. An increase in yield is only the case if cavitation can further disrupt otherwise inaccessible cell membrane structures and long chain organic molecules. In this study the influence of hydrodynamic cavitation on sludge that was already digested for 30 days was investigated. The total biogas yield could indeed be increased. The effect of the backpressure behind the venturi tube on the yield could not yet be established.

1. Introduction
Cavitation bubbles have the tendency to adhere to surfaces like cell membranes as well as to long chain molecules, and the stress exerted upon these surfaces during implosion of the bubbles leads to their disruption. Cavitation can therefore be applied to improve the extraction of valuable ingredients from cells, as in the extraction of carotene from alginate cells [1]. Cavitation can also be used to accelerate and enhance biogas production from municipal waste activated sludge by anaerobic bacteria [2-3]. Waste activated sludge is also called secondary sludge and comes from domestic waste after treatment with aerobic bacteria. There are several methods to induce cavitation. The most frequently applied techniques are ultrasound [4-5], and hydrodynamic cavitation [6-7]. For these methods the energies needed to achieve an improvement of about 20% in biogas production were compared [2]. Hydrodynamic cavitation requires a substantially lower energy input. In these studies however, where the beneficial effect of cavitation was tested, it became not fully clear whether cavitation increases the total biogas yield or only the digestion rate. The aim of this study is to demonstrate whether cavitation indeed increases the biogas yield. For this proof cavitation was applied on sludge after long-term digestion by anaerobic bacteria. The most easily digestible organics are by then converted, and further production of biogas should come from conversion of membrane structures disrupted by cavitation and from disrupted long chain organic molecules. A second objective is to investigate whether an increase in pressure at the outlet of the hydrodynamic cavitation tool, here chosen to be a venturi tube, could increase the biogas production at the same pressure drop over the tool. Calculations have shown that an increase in backpressure behind a cavitation tool, leads to a higher collapse pressure [8], and thus a stronger disruption of membrane structures is expected.
2. 50 Bar test circuit
A closed loop stainless test circuit with a total volume of 0.26 m$^3$ was constructed that could stand a working pressure of 50 bar. A venturi tube with a convergent inlet (31°) with a diameter decreasing from 46 mm to a 5 mm and a divergent outlet (90°) with a diameter increasing up to 12 mm was hanging in a test chamber with a diameter of 300 mm. The outlet of the tube in the test chamber was illuminated and could be watched through a viewing window. A flow was circulated through the venturi tube where cavitation could be induced by a pressure drop over the tube maintained by two centrifugal pumps (Grundfos, CRN 10-21SF, CRN 10-20) lined up in series. The backpressure in the test chamber could be increased up to 10 bar by use of a pressure accumulator at the top of the chamber. The maximum flow rate through the venturi tube was 6 m$^3$/h at a pressure drop of 40 bar.

3. Results and Discussion
First of all the zone was established where at various backpressures the flow rate sufficed to induce low pressure cavitation bubbles in the venturi tube. The presence cavitation and the size of the plume of cavitation bubbles leaving the tube outlet could only be determined by visual observation through the viewing window.

This cavitation zone was measured for water, because digested sludge is not transparent. Sludge has about the same density as water and only a slightly higher viscosity at a solid weight percentage of 2.5. So no large shift in position of the cavitation zone is expected for sludge.

In figure 1 the flow rate is plotted against the backpressure for experiments where the flow rate was gradually increased at backpressures between 2.5 and 9 barg. At flow rates above the dotted line cavitation was observed. The higher the flow rate the denser and longer the observed cavitation plume at a given backpressure became. This can be seen by comparing figure 1b and 1c both at a backpressure of 2.9 barg. In figure 1b the flow rate is 4 m$^3$/hr which lies about 0.5 m$^3$/hr above the dotted cavitation line, and in figure 1c the flow rate is 5 m$^3$/hr. In figure 1d the flow rate is 6 m$^3$/hr at a backpressure of 8.7 barg, which is also about 0.5 m$^3$/hr above the cavitation line, and the observed plume resembles the plume in figure 1b.

Digested sludge from the wastewater plant Houtrust in the Netherlands was used for the subsequent experiments. This sludge resulted from digestion by anaerobic bacteria for 30 days. Before use this digested sludge was filtered over a 4 mm size filter to prevent blockage of the venturi tube that is 5 mm wide at its narrowest cross-section. This sludge was circulated 50, 75 or 100 times over the venturi tube at a flow rate that was sufficiently high above the dotted cavitation line for water at the selected backpressure to induce cavitation. Although no cavitation could be visually observed, its occurrence was audible. After treatment of the digested sludge with cavitation the biochemical methane potential (BMP) was determined for comparison with the BMP of untreated digested sludge (the blanc). The results for two backpressure and flow rate conditions of respectively 2.9 barg and 5 m$^3$/hr and 8.5 barg and 6 m$^3$/hr, indicated by the red triangles in figure 1a, are presented in figure 2a and b. For the two conditions with flow rates of 5 and 6 m$^3$/hr similar cavitation plumes are expected as seen in figure 1c and 1d.
Before the methane production was measured 100 g sludge sample was mixed with 100 g untreated digested sludge as inoculum before it was fed into the AMPTS vessel. This inoculation was added in order to have enough anaerobic bacteria available for conversion of the organics. The mixture was kept at 36°C and the methane production was measured over time for the digested sludge treated by cavitation under two operating conditions at three recirculation times as well as for the blanc. These results are presented in figure 2 after subtraction of the methane produced from the added inoculum itself. Comparison of the methane production during the first day most clearly shows that treatment of the sludge by cavitation strongly accelerates the conversion into methane. In figure 2a it is shown that the methane production increased about a 100% from 42 to 85 ml during the first day for a 100 times recirculation, while the total methane production after 11 days increased by about 50% from 153 to 232 ml. The effect of recirculation on the methane yield is also evident. When the recirculation is lowered to 75x or 50x the production rate and total production after 11 days are lowered proportionally.

**Figure 1.** a) plot of flow rates versus backpressure and the absence or occurrence of cavitation in water; b and c) cavitation plumes in water at a backpressure of 2.9 barg and flow rates of respectively 4 m³/hr and 5 m³/hr; d) cavitation plume at a backpressure of 8.7 barg and a flow rate of 6 m³/hr.

**Figure 2.** Methane production of digested sludge with cavitation at a backpressure of (a) 8.5 barg and a flow rate of 6 m³/hand of (b) 2.9 barg and 5 m³/hr. 0x implies that the sludge is not cavitated as in the blanc.
With a backpressure of 2.9 bar and 100 times recirculation in figure 2b a more or less similar acceleration in methane production after the first day (110%) and increase in production after 11 days of about 66% can be seen as for the backpressure of 8.5 bar. But now the production rate and total yield after 11 days are lowered more at 75x and 50x recirculation than predicted by the proportional reduction in recirculation times.

Although a comparison between the results for both backpressures is not fully allowed because of the difference in flow rate, it can be observed that the total methane yield after 11 days is about equal for a 75 and 100 times recirculation. For 50 times recirculation the higher backpressure gives a better yield. At a higher backpressure, however the required energy input for an open circuit would become higher.

4. Conclusions
From these experiments with high recirculation times it can be concluded that treatment with cavitation further disrupts cell membranes and long chain molecules and makes more organic material accessible for conversion by anaerobic bacteria. It, however, remains undecided if for digested sludge and high recirculation times a higher backpressure is beneficial. Especially because more energy is required for cavitation in an open circuit at a higher back pressure.

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