Using biogas as fuel in vehicles requires exclusion of carbon dioxide and can be accomplished through a desorption process where air removes the carbon dioxide from the sludge, used to produce biogas. A high air flow rate, low constant pH, high alkalinity, low pressure, high temperature, high stirrer speed and using a packed column was expected to have an positive influence on the process and was therefore chosen to be examined. However, experiments concerning high temperature and packed column were not performed. The optimal value for the air flow rate resulted in 200 ml/min and the constant pH in 5.5. A higher flow rate contributed to bubble coalescence while a lower generated an impaired desorption. The graphs for the pressure experiments indicated that the lowest tested pressure, 0.7 atmospheres, appeared most favorable. Nevertheless, extracting samples from the decompressed system was difficult and as a consequence, fluctuation occurred in the result and an optimal value was not decided. Although a high stirrer speed had a visibly desirable effect, the actual speed was not registered and optimal value remains to be determined. Lastly, the high alkalinity was not proven to generate the positive effect expected.

INTRODUCTION

Biogas is a gaseous mixture of mainly methane and carbon dioxide and is the results of an anaerobic digestion of organic matter. A reduction of carbon dioxide in the gas would enhance the efficiency of biogas and enables the usage as fuel in vehicles (Lindberg – Rasmuson, 2006). A literature study showed that the removal of carbon dioxide from the sludge, producing the biogas, appeared most beneficial. Using a desorption column where air enters and desorbs the carbon dioxide from the liquid enables a purified sludge to be recycled to the digester (Lindberg – Rasmuson, 2006).

Parameters

Numerous parameters were predicted to effect the desorption of carbon dioxide and as a consequence the aim of the study was concentrated to which parameters would lead to an improved desorption and what impact the design of the column has on the process.

The air flow influences the desorption depending on the rate. A rather low gas velocity contributes to a homogenous flow with small bubbles while a higher flow rate can result in bubble coalescence (Lindberg – Rasmuson, 2006). Moreover, within the homogenous flow, the gas-liquid surface area increases with increasing air flow rate and consequently the amount of desorbed carbon dioxide increases (Lei et al., 2007).

The pH in the liquid reflects the amount of carbon dioxide available. Equations 1 to 3 illustrate the reactions taking place in the system and are highly influenced by the pH, stated by Lindberg – Rasmuson (2007) and Lei et al. (2007).

\[
CO_2(aq) \leftrightarrow CO_2(g) \tag{1}
\]
\[
H^+(aq) + HCO_3^-(aq) \leftrightarrow CO_2(aq) + H_2O(l) \tag{2}
\]
\[
H^+(aq) + CO_3^{2-}(aq) \leftrightarrow HCO_3^-(aq) \tag{3}
\]

At lower pH values the solubility of carbon dioxide in the liquid decreases and the reactions proceed to the right, increasing the amount of gaseous carbon dioxide to be carried off by the air (Richards et al., 1994). Nevertheless, during the desorption process the hydrogen ions, in reaction 2, are consumed and the pH is increased (Lei et al., 2007).

The Alkalinity was expressed with equation 4 received by Tchobanoglous et al. (2003).

\[
Alk = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] – [H^+] \tag{4}
\]
Since equation 1 to 3 describes how the consumption of one component contributes to another one being formed, the alkalinity is not affected by the desorption process (Summerfelt et al., 2003). The influence of adding a strong acid is however considered by Holmes (2002) who states that the alkalinity will be reduced.

If the alkalinity is believed to represent the buffer capacity of the system, the pH changes caused by removal of carbon dioxide would not affect the desorption when using a higher alkalinity (Tchobanoglous et al., 2003).

The pressure, like the pH, influences the solubility of carbon dioxide. A decompression results in a super saturation of the liquid which as a consequence rapidly releases the carbon dioxide to the gas phase. However, the pressure is again increased when the carbon dioxide is removed from the liquid (Kierzkowska – Chacuk, 2010).

The temperature is dependent on the digestion process. Hilkiah Igoni et al. (2008) argue that an increased temperature increases the methane production. Moreover, Pande – Fabiani (1989) adds that the desorption rate is significantly increased. Lastly, the time for aeration is also expected to be reduced (Lei et al., 2007). However, a higher temperature also results in an unstable digestion process due to the sensitivity of the bacteria and the mesophilic temperature range, 30 – 38 °C, is therefore commonly used (Hilkiah Igoni et al., 2008).

The stirrer and the stone diffuser affect the mass transfer of the carbon dioxide from the liquid to the gas.

A stirrer creates turbulence in the liquid, increasing the mass transfer (Kierzkowska – Chacuk, 2010). Sun et al. (2010) examined the most favorable position of the stirrer and concluded that a stirrer placed centrally, at the bottom of a bottle would be most desirable. Although an increased stirrer speed naturally would generate greater turbulence a too high value provides an unfavorable mixing (Kierzkowska – Chacuk, 2010).

Additionally, smaller bubble diameter, as a results of a homogenous flow, created with the help of a stone diffuser (Lindberg – Rasmuson, 2006), increases the specific bubble surface and therefore the mass transfer (Merkel – Krauth, 1999).

A packed column can reduce the liquid back mixing which is a major drawback of a bubble column (Carleton et al., 1967). Moreover, reduced bubble coalescence followed by an increased mass transfer can be expected (Carleton et al., 1967). Furthermore, Carleton et al. (1967) concludes that the additional pressure drop caused by a packed column is negligible.

Moreover, large void spaces in a structured packing can diminish the bio fouling problems as a result of using a packed column according to Summerfelt et al. (2003).

EXPERIMENTAL WORK

The experiments were performed in the laboratory of Bioprocess Control AB. The liquid containing dissolved carbon dioxide was prepared with a soda streamer. A 2000 ml bottle was used as a bubble column and a pump delivered the air to the system through a stone diffuser. The air flow rate was measured with the help of a flow meter. A magnetic stirrer was placed at the bottom of the bottle. Furthermore, a probe was used to measure pH in the liquid. A pressure sensor registered the pressure and was regulated by a vacuum pump. Finally, samples were extracted from the outlet and analyzed in the gas chromatograph.

Temperature and packed column experiments were not performed due to limitation of time and equipment. Hence, all experiments were conducted in ambient temperature (22 °C). Each parameter was tested one at a time.

The air flow rates used were 100 ml/min, 200 ml/min and 300 ml/min while constant pH values of 5.5, 6.0 and 6.5 were applied. Moreover, constant pressure values of 0.7, 0.8 and 0.9 atmosphere were examined along with a diffusion experiment. Lastly, low and high stirrer speeds were studied with the stone diffuser removed. All experiments were performed in a 20 mM and an 80mM calcium carbonate buffer solution.
RESULTS AND DISCUSSION

Not being able to control the initial amount of carbon dioxide in the solution resulted in aggravated comparisons. Also, the higher alkalinity solution generated lower maximum values of desorbed carbon dioxide and is assumed to be a result of a lower amount of initial carbon dioxide added to the solution. The assumption is confirmed when comparing the pH graphs for the two alkalinities since the 80 mM solution starts at a higher pH indicating less carbon dioxide.

Results from the air flow rate changes showed that although an increase from the air flow rate 100 ml/min to 200 ml/min favored the desorption, an increase to 300 ml/min lacked the same result, depicted in figure 1.

Both solutions showed similar results and the air flow rate 300 ml/min therefore seems to result in bubble coalescence.

Results from the pH changes proved that lower pH values generated higher maximum values and shorter desorption times, depicted in figure 2. The pH values were achieved by adding 3 M hydrochloric acid, HCl, or 3 M sodium hydroxide. In order to counteract the increase in pH during the desorption, 0.5 M HCl was automatically added.

Results from the alkalinity measurements confirmed that the alkalinity remained unaltered after the desorption. However, measuring the alkalinity after adding hydrochloric acid resulted in a reduced alkalinity. The absence of a difference in the desorption graphs for the two solutions indicate that the effect of the higher alkalinity was not detectable. A higher alkalinity solution consists of added cations which may interact with the dissolved carbon dioxide and can be the reason to the 80 mM solution not resulting in an improved desorption.

Results from the pressure changes and the diffusion are depicted in figure 3.

A low pressure complicated the extraction of samples and as a result fluctuations occurred. Nonetheless, figure 3 illustrates higher maximum values for the lower pressure values. The diffusion...
is as desired much lower. Examining the pH graphs however, indicates a lower amount of initial carbon dioxide. Regardless, the marginally higher pH is not considered to correspond to the large difference in the desorption graphs.

Results from the stirrer speed changes showed that higher stirrer speeds improves the desorption in both solution although more distinctly in the lower alkalinity solution.

CONCLUSIONS

The design of the column was considered in terms of using a packed column instead of an empty. The reduced liquid back mixing as well as less bubble coalescence would improve the desorption. The hypothesis was however not confirmed by experiments.

The conclusions from the results for the six parameters considered follow below:

- The optimal value for the air flow rate in the experiments was 200 ml/min since both the higher and lower rate resulted in worsened desorption.
- The constant pH 5.5 was proven, through experiments, to create a better desorption than having higher values.
- The alkalinity did not show any effect on the desorption in the experiments carried out.
- The graphs generated from the pressure changes indicated that lower values are preferable. However, an optimal value could unfortunately not be decided since fluctuations occurred.
- The improved desorption caused by an increased stirrer speed was apparent. Nevertheless, an optimal value was unattainable since no actual values were obtained.
- Finally, high temperature values are predicted to improve the desorption. An optimal value was not decided since the parameter was not experimentally tested.

Future research primarily comprises testing of the mentioned parameters in a real sludge and on a larger scale to examine if any side reactions occur and if the parameters generate the same results.

REFERENCES


