# Methane Generation from Anaerobic Digesters: Considering Different Substrates

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## ABSTRACT

Anaerobic digestion can breakdown waste and produce a useful by-product of biogas that can be used for heating and lighting. Presenting research material from around the world and using a variety of different methods and substrates, this paper strives to demonstrate the effect of anaerobic digestion on wastes in the relation to methane generation. In particular, three specific parameters were examined both before and after undergoing anaerobic digestion. Ammonia-nitrogen, volatile fatty acids, and total solids and volatile solids were all looked at in turn. These three processes were paired with their corresponding values of the production of methane gas. Overall, it was found that the lowest final ammonia-nitrogen concentrations did not have the highest methane production. The lowest concentration of volatile fatty acids (VFA) also did not correspond to the highest methane production. While data was difficult to interpret with respect to the total solids (TS) and volatile solids (VS), it was found that a higher ratio of TS/VS matched a higher value of methane production. These parameters are of concern if anaerobic digestion is the sole treatment for wastes which are then applied to the land.



**KEYWORDS**
Biogas; Methane Production; Anaerobic Digesters; Ammonia-Nitrogen; Volatile Fatty Acids; Total Solids; Volatile Solids


## INTRODUCTION

Anaerobic digestion of biomass is an efficient way to not only break down wastes with high organic content, but can also produce biogas, a good fuel source similar to natural gas containing methane. This fuel can be produced with every flush of the toilet; it only needs to be harnessed. The European Union (EU) is striving for more renewable sources of energy in efforts to decrease their use of fossil fuels and meet the Kyoto Protocol (EU Commission of Energy, 2005). Some places have gone to extreme to declare themselves as a “Fossil Fuel Free Municipality”, such as Kristianstad, Sweden that became fossil fuel-free in 1999 (Renewable Energy for Europe, 1999). Part of Kristianstad’s energy needs is met through biogas from local agricultural wastes and manure. Many developing countries use biogas for energy, especially for stoves and lighting in rural areas. China has been using biogas technology for over 30 years. India and Africa have also been using biogas to provide for their populations. Indeed, the research with methane production due to anaerobic digestion is from such diverse places as Illinois, England, India, Turkey, Korea, and Egypt.

Biogas provides not only a source of energy, but the anaerobic digestion process helps to treat the wastes. Anaerobic digestion can stabilize the waste material to a product that is rich in nutrients and can be used as a soil fertilizer or conditioner depending on what the waste breaks into (wikipedia.org, 2005). The use of anaerobic digesters is widespread throughout the world for many different sources of wastes. The use of biogas is relatively novel idea for the United States, and as a new form of energy is in higher demand due to the rising cost of oil and natural gas, biogas appears to be a good alternative at it is relatively cheap and locally available.

The past twenty years have seen many papers about biogas production, all looking at different substrates to the digester and the effects of various other factors (temperature, pH, etc). The purpose of this paper is to focus on three distinct characteristics of waste and their relation to methane production, specifically the effect on ammonia-nitrogen, volatile fatty acids, and total/volatile solids. Ammonia-nitrogen was chosen as a focus in this paper because the leachate of nitrogen can negatively affect surrounding waters and while few regulations currently exist on nitrogen, there might be more stringent permits in the near future. Volatile fatty acids (VFA) were examined because they are an integral step in the production of methane. In a few steps, bacteria can breakdown proteins, carbohydrates, and fats and oils into VFA which can used to make other acids releasing biogas as a side product (Harris, 2005). Volatile solids

(VS) and total solids (TS) are important criteria when loading an anaerobic digester. The VS can be considered as a measure of the organic matter and TS is used to help determine which digester is adequate for the amount of waste coming in (Schmidt, 2005).

## TYPES OF ANAEROBIC DIGESTERS

It is necessary to point out the variety of anaerobic digesters available for use throughout the world. Of the studies referenced in this paper, research was preformed using two main types of reactors: mixed or batch. A mixed reactor ensures contact between the substrate and the bacteria. This type includes the completely stirred tank reactors (CSTR) that are virtually 100% mixed. Mixed reactors often run continuously, meaning that substrate is added at certain intervals and effluent is removed after a pre-determined time. Batch reactors are started with a given amount of substrate and left to react for a specified hydraulic retention time. Batch reactors can be run on a continuous or semi-continuous basis, but are often non-continuous, meaning they are fed once and left to react.

It was noted by Carucci *et al*. (2005) that in North America, more aerobic compost plants than anaerobic digesters are currently being used to treat solid wastes. Several reasons were cited for this trend, including: the higher initial investments needed for anaerobic digesters, the trained and skilled personnel required to be on hand for any troubleshooting, and the occasional need for further aerobic post-treatment of anaerobic biosolids.

## FACTORS AFFECTING METHANE PRODUCTION

There are many variables that affect the methane production of substrates during the process of anaerobic digestion. The most obvious one is the different substrates and proportions of substrates added. The differing diet of animals affects the composure of their manures and wastes which can further complicate obtaining a homogeneous substrate. Also, different species of animals have different properties of wastes (i.e. ammonia content) which can affect the degree of digestion. The variance of materials in the municipal or industrial waste also needs to be considered as the contents of the starting product impact the end result of digestion. Plant material is especially hard for bacteria to break down, especially the lignin and chitin of woodier and aged plants. Despite all these differences in substrates, this paper will consider the overall effect of anaerobic digestion on the ammonia-nitrogen, volatile fatty acids, and total and volatile solids and the methane production.

It is necessary to understand at least briefly the effects of various other factors on methane production. For the reason to ensure a knowledgeable reader, some major variables in affecting the methane production during anaerobic digestion will be discussed briefly. An interested reader can find more information in other papers or publications to quench the thirst for knowledge.

### *Temperature*

There are different ranges of temperature that are optimal for the different varieties of methanogens. The research done by El-Mashad, *et al*. (2004) looked at the affect of specifically thermophilic bacteria. Higher temperatures speed up the reaction and allow for a shorter hydraulic retention time. It was shown that the maximum specific methanogenic activity of the effluent was best at 50°C when compared to 60°C, 30°C, or 40°C. When the temperature was between 50-60°C, El-Mashad *et al* (2004) noted that hydrolysis was negatively affected, possibly causing an increase of $NH_3$ which in turn negatively affected the menthanogenesis. To counteract the effects of a fluctuating temperature, the anaerobic digester was kept at a steady temperature throughout many of the tests. The mesophilic methanogens were used in most of the other studies. Often the temperature was held constant to negate the effects of changing, with the most common temperature of 35°C.

*pH*

The optimum pH for methanogenic bacteria is in the neutral to slightly basic range. It has been shown that the rate of methane production declines when the pH value falls below 6.3 or becomes greater than 7.8 (El-Mashad *et al*, 2004). Many of the research teams discussed in this paper controlled the effects of a fluctuating pH by monitoring the pH and keeping it stable by the addition of an acid or base as needed.

*Hydraulic Retention Time (HRT)*

The amount of time a material substrate spends in the digester obviously has a large effect on the anaerobic digestion process. The longer the HRT, the more likely the substrate will be broken down and stabilized and have proper interactions with the bacteria within the digester. Hence, a longer HRT leads to increased methane production. Having a longer HRT can also affect the size of the digester, as a long time requires a larger digester and has lower turnover rate. Although some studies also looked at the HRT, many set it as a constant ranging from 1 to 20 days. A few studies maintained the digestion until the production of methane fell or leveled off.

## AMMONIA-NITROGEN

High ammonia concentrations can be very toxic for anaerobic bacteria and can inhibit the production of methane (Tada, *et al.*, 2005). Ammonia concentrations tend to be high in cattle manure and other livestock wastes with high percentages of organics. To counteract this, organic wastes are usually diluted with water, but the dilution adds more volume of waste causing an increase in size and making the digester more expensive (Tada, *et al.*, 2005).

The study done by Tada, *et al.* (2004) made ammonia rich sludge with a beginning concentration of 3154 mg N/L. Different additives were mixed with eight of the nine trials run during this study. The goal was to determine the best way to promote ammonia removal during digestion. After twelve days of the experiment the lowest concentration of nitrogen was approximately 525 mg N/L, which constituents a substantial decrease. However, it is interesting to note that this additive also produced the least methane gas—even less then the control trial. The most methane was produced by sludge that had only decreased to 650 mg N/L at just over 70 mL methane/g VS.

While the study by Tada *et al.* (2004) gives some explanation as to the effect of ammonium-nitrogen on the production of methane, it is necessary to consider the data by other studies. El-Mashad *et al.* (2004) cited final ammonia-nitrogen concentrations ranging from 854.4-1138.9 mg/L, substantially higher than the study by Tada *et al* (2004). However, the general results are the same as the higher ammonia-nitrogen final values corresponded with lower methane production.

Dilute swine waste was the topic of a paper by Hill and Bolte (2000) considering five different hydraulic retention times. Oddly, the amount of ammonia-nitrogen actually increased during the study. This can in part be explained to the fact that the waste started as dilute and then was concentrated during the digestion process. The lowest final value of ammonia-nitrogen was 535.8 mg-N/L by a trial with a two day HRT. Again, the trial with the slightly higher ammonia-nitrogen concentration (of 665.3 mg-N/L) had a higher methane production. The difference between the methane productions was slight, only about 100 L/kg $VS_{destroyed}$, quite different than the vast disparity between the study by Tada *et al.* (2004).

A study on high-paper municipal and industrial waste by Oleszkiewicz and Poggi-Varaldo (1997) found that the lowest final ammonia-nitrogen concentration also corresponded to the highest production of methane. In the three trials done by the duo, the theory that the lower the ammonia-nitrogen concentration at the end the higher the methane production would be are all supported. The range of final ammonia-nitrogen is 0.82 to 2.4 g/kg digesting solids. It should be noted that digesting solids are not adequately explained in the paper, and thus the terminology is maintained in order to prevent manipulation of the data.

Parawira *et al.* (2004) researched the methane production of potatoes and sugar beet leaves for biogas production in Zimbabwe. Their study echoed Oleszkiewicz and Poggi-Varaldo as the lowest ammonia-nitrogen concentration corresponded to the highest methane production. For that particular trial, the mix had a total solids of 24% potato waste and 16% sugar beet leaves. A total of nine different combinations of potato waste and sugar beet leaves were tried.

A study from Misi and Forster (2001) featured two different trials, each of seven different mixtures of wastes. Trial A had mixes of cow dung, chicken manure, and molasses, with the highest methane production from 50% cow dung and 50% molasses substrate. The lowest ammonia-nitrogen in the effluent was from a 100% cow dung substrate. In Trial B, cow dung, chicken manure, fruit and vegetable waste, sheep and goat manure, and thickened waste activated sludge were mixed. The lowest ammonia-nitrogen concentration at the end was also the trial that had the least decrease in ammonia-nitrogen. It was for a mixture of 15% fruit and vegetable waste, 15% cow dung, and 70% sheep and goat manure. The highest methane production was found using a mix of 15% fruit and vegetable waste, 15% cow dung, and 70% chicken manure, illustrating the subtle difference between sheep and goat manure and chicken manure. It should also be noted that in all trials, the last trial produced the most methane.

Table 1 summarizes these results, illustrating the differences in the studies when comparing a decrease of ammonia-nitrogen and production of biomass. When necessary, small calculations were done to give the results in common units. Many calculations were simply changing units (i.e. from g to kg). The study by Misi and Forester (2001) needed slightly more work. It was impossible to convert the percentages of methane to mL/g VS from the El-Mashad *et al.* (2004) study due to lack of data provided.

**Table 1. Results of Ammonia-Nitrogen and Production of Methane.**

| Study | | Initial $NH_3$-N | Final $NH_3$-N | Production of Methane |
|---|---|---|---|---|
| Tada *et al.* (2004) | | 3154 mg/L | | |
| | Lowest $NH_3$-N | | 525 mg/L | 32 mL/g VS* |
| | Highest $CH_4$ | | 650 mg/L | 71 mL/g VS* |
| El-Mashad *et al.* (2004) | Lowest $NH_3$-N | | 967.8 mg/L | 34.20% |
| | Highest $CH_4$ | | 1056.9 mg/L | 38.80% |
| Hill and Bolte (2000) | Lowest $NH_3$-N | 424.5 mg-N/L | 535.8 mg-N/L | 600 L/kg $VS_{destroyed}$ |
| | Highest $CH_4$ | 400.1 mg-N/L | 665.3 mg-N/L | 710 L/kg $VS_{destroyed}$ |
| Oleszkiewicz and Poggi-Varaldo (1997) | Lowest $NH_3$-N<br>Highest $CH_4$ | 0.359 g/kg digesting solids | 0.82 g/kg digesting solids | 302 L/kg $VS_{fed}$ |
| Parawira *et al.* (2004) | Lowest $NH_3$-N<br>Highest $CH_4$ | 700 mg/L | 1000 mg/L | 680 L/kg $VS_{degraded}$ |
| Misi and Forster (2001) | Lowest $NH_3$-N (A) | 419 mg/L | 112 mg/L | 546 L/kg $VS_{destroyed}$ |
| | Highest $CH_4$ (A) | 349.5 mg/L | 279.5 mg/L | 564 L/kg $VS_{destroyed}$ |
| | Lowest $NH_3$-N (B) | 267 mg/L | 254 mg/L | 420 L/kg $VS_{destroyed}$ |
| | Highest $CH_4$ (B) | 996 mg/L | 677.5 mg/L | 570 L/kg $VS_{destroyed}$ |

*Study does not indicate if values are $VS_{fed}$ or $VS_{destroyed}$

**VOLATILE FATTY ACIDS**

Volatile fatty acid accumulation can lead to a drop in pH, which inhibits the microorganisms. A continual drop in pH can ultimately cause failure in an anaerobic digester. VFA are needed in small amounts as part of an intermediary step for the metabolic pathway of methane production by the methanogens (Carucci *et al*. 2005). That conclusion was supported by El-Mashad *et al.* (2004) who referenced a paper done by Georgacakis *et al.* (1982) stating that VFA is one of the three primary buffer-agents needed for maintaining the pH value, and hence the ammonia concentration. (The original paper by Georgacakis proved difficult to find.) El-Mashad *et al.* (2004) preformed their study with diluted dairy cow manure, varying the temperature and the hydraulic retention time. The lowest VFA after digestion was the one kept at 50°C with a HRT of 20 days, although it did have the second to lowest methane production. Given the need for VFA during the production of methane, it should be noted that the highest methane producing substrate corresponded to the second highest final VFA concentration.

Møllera *et al.* (2004) considered the difference in productivity of different types of manure and straw. Their data was split into category of animal: cattle, pig, and sow and then subdivided on the feed of that animal. For the cow, the highest methane production corresponded with by far the highest VFA (82.53 g/kg VS compared to the average for all seven cows of 35.85 g/kg VS). The difference between feed of the cattle was not very great to warrant such a dramatic increase in VFA. The lowest VFA was substantially lower than 82.53 g/kg VS, the highest methane producing sample. Although the methane produced by the lowest VFA was not far off the maximum value. For the pig data, a close second highest VFA gave the highest production of methane. Again, the lowest VFA produced similar results in the production of methane. The sow trials produced similar amounts of methane to the pig trials, but the final VFA was almost a third the size of a pig. The lowest VFA also had the highest methane production.

Another study concerning the anaerobic digestion of animal waste and mixing was done by Karim *et al.* (2005). In this case biogas was recirculated through the digester and the length of a draft tube for the anaerobic digester was varied. The highest biogas produced was the digester that had a shorter draft tube height; this trial also had the lowest VFA.

Hill and Bolte (2000) ran experiments using swine waste. They found that with a two day HRT, the lowest VFA was found to be 459.5 as acetic acid mg/L. As noted before, the highest methane production corresponded to the highest final VFA. However, in this case there was a larger difference between the amounts of methane produced from the two trials. It should be noted that the data by Hill and Bolte (2000) gave the highest values for the production of methane than any of the other data sets.

Table 2 shows a summary of the results as stated above. The data by El-Mashad *et al.* (2004) could not be converted easily into similar units. Similar difficulties were found from the Karim *et al.* (2005) paper, due to the lack of information offered to the reader.

**Table 2. Results of Volatile Fatty Acids and Methane Production.**

| Study | | Final VFA | Production of Methane |
|---|---|---|---|
| El-Mashad *et al.* (2004) | Lowest VFA | 63.2 mg [COD]/L | 27.50% |
| | Highest $CH_4$ | 201.1 mg [COD]/L | 38.80% |
| Møllera *et al.* (2004) | Lowest VFA (cattle) | 11.19 g/kg VS | 464 L methane/g VS |
| | Highest $CH_4$ (cattle) | 82.53 g/kg VS | 480 L methane/g VS |
| | Lowest VFA (pig) | 62.62 g/kg VS | 514 L methane/g VS |
| | Highest $CH_4$ (pig) | 78.52 g/kg VS | 532 L methane/g VS |
| | Lowest VFA (sow) | | |
| | Highest $CH_4$ (sow) | 27.76 g/kg VS | 536 L methane/g VS |
| Karim *et al.* (2005) | Lowest VFA<br>Highest $CH_4$ | 0.01 g/L | 0.69 L/L-day |
| Hill and Bolte (2000) | Lowest VFA<br>Highest $CH_4$ | 459.5 as acetic acid mg/L | 600 L/kg $VS_{destroyed}$ |
| | Highest VFA | 644.3 as acetic acid mg/L | 710 L/kg $VS_{destroyed}$ |

**TOTAL SOLIDS AND VOLATILE SOLIDS**

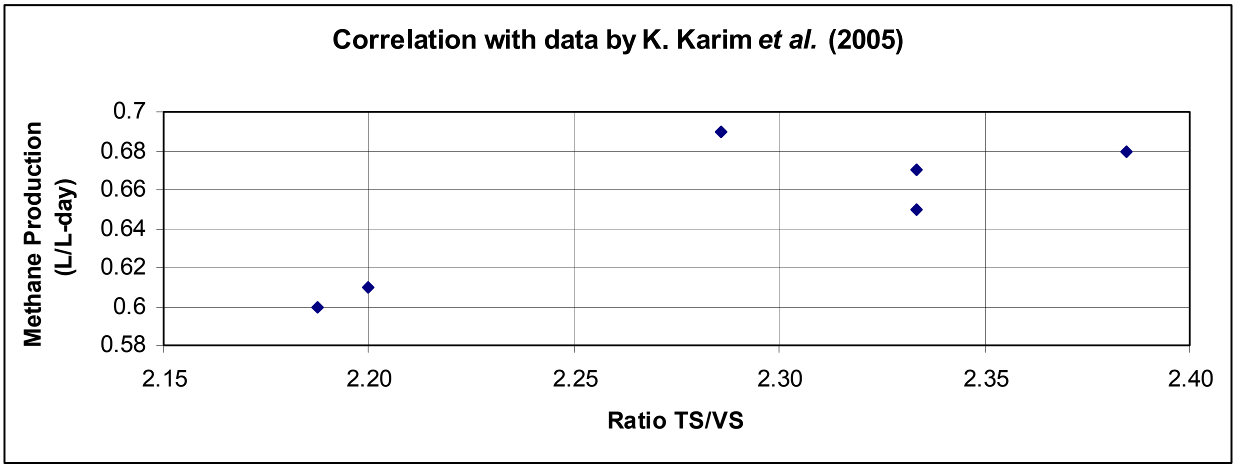
Total solids and volatile solids are important parameters as they can help determine the characteristics of the sludge. Total solids are used to determine the loading rate of the anaerobic digester and give clues as to when maintenance is needed. Typically, total solids amount to less than 10% of the total volume. The volatile solids content can give an estimate on the amount of substrate that can potentially be turned into methane (Wilkie, 2003). It only gives an estimate because volatile solids are made up of different organic compounds that have varying degradability speeds.

The study by El-Mashad *et al.* (2004) did not list the final results of TS or VS, but did indicate that TS was within the average range at 5%. The ratio of the TS/VS was just slightly over one. For this trial, the HRT was 20 days and thermophilic bacteria were used.

Møller *et al.* (2004) found that the average cow had a bit more than a third the TS of a sow, and about half the TS of a pig. The cow also had the least methane production than the other animals. Volatile solids for the three species were quite similar, not varying much more than 100 g/L from an average. The ratios of TS/VS for all three trials were quite a bit lower than 1.0. The lowest ratio corresponded to the lowest methane production, but the highest ratio only gave the second highest methane production.

The results of Karim *et al.* (2005) found a general trend that as the ratio of TS/VS increased, the amount of methane produced also increased. This result is best illustrated by Figure 1. Karim *et al.* (2005) used the recirculation of biogas through their system, varying only the dimensions of the set-up and the HRT.

**Figure 1. Graph showing the Correlation between TS/VS and Methane Production.**




Hill and Bolte (2000) studied the effects of HRT on the production of methane. Their data is hard to draw conclusions from, as the different HRTs affect the production of methane. However, looking at the ratios of the TS/VS the lowest ratio corresponds to the lowest production of methane. As in the study by Møller *et al.* (2004), the highest ratio corresponded to the second highest methane production.

Griffin *et al*. (1997) looked at start-up of an anaerobic digester for municipal solid wastes (MSW). The test used a mix of organic-fraction of MSW, primary sludge, and waste activated sludge. The pH was controlled during this study with the addition of acid or base. They considered two types of digesters varied by temperature: mesophilic (with a constant temperature of 37˚C) and thermophilic (with a constant temperature of 55˚C). The methane production was very similar between the two digesters; the highest ratio of TS/VS corresponded to the highest production of methane.

Oleszkiewicz and Poggi-Varaldo (1997) also did an experiment with municipal wastes, although they were more focused on high solids waste. In this case, the results were opposite to what was found before. The lowest ratio of TS/VS corresponded to the highest production of methane and the highest TS/VS ratio gave the lowest methane production. However, looking at the ratio can be somewhat deceiving as, "Intuitively, higher temperature and longer duration work(s) toward increased VS destruction" (Oleszkiewicz and Poggi-Varaldo, 1997). Thus, their results could be due to other parameters changing and affecting the methane production more dramatically than the amounts of TS and VS.

Jokela *et al.* (2005) did a study on the different components of grey waste, a part of municipal solid wastes in Finland. They sorted the components into nine different categories, but did not take the TS or VS of all the categories individually. Thus, only the results for office paper can be included in this study. The amount of methane produced is comparable to the results of Oleszkiewicz and Poggi-Varaldo (1997) despite the fact that the TS/VS ratio is smaller.

Table 3 shows the results of the studies mentioned above. When possible, units were changed to be similar, but often data was not clearly stated in the original papers. This is why the ratio of TS/VS was taken to give a better tool for comparison purposes.

**Table 3. Results of TS/VS and Methane Production.**

| Study | | Initial TS | Final TS | Initial VS | Final VS | Ratio of TS/VS | Methane Production |
|---|---|---|---|---|---|---|---|
| El-Mashad *et al.* (2004) | | 50 g/L (5%) | | 40.7 g/L | | 1.23 | 31.50% |
| Møllera *et al.* (2004) | Avg. Cow | 122.53 g/L | | 895.23 g/L | | 0.14 | 148 L $CH_4$/g VS |
| | Avg. Pig | 223.39 g/L | | 848.66 g/L | | 0.26 | 356 L $CH_4$/g VS |
| | Avg. Sow | 311.00 g/L | | 791.63 g/L | | 0.39 | 275 L $CH_4$/g VS |
| Karim *et al.* (2005) | | 3.10% | | 1.30% | | 2.38 | 0.68 L/L-day |
| | | 3.50% | | 1.50% | | 2.33 | 0.67 L/L-day |
| | | 3.20% | | 1.40% | | 2.29 | 0.69 L/L-day |
| | | 3.50% | | 1.60% | | 2.19 | 0.60 L/L-day |
| | | 3.30% | | 1.50% | | 2.2 | 0.61 L/L-day |
| | | 3.50% | | 1.50% | | 2.33 | 0.65 L/L-day |
| Hill and Bolte (2000) | HRT 5 days | 19.2 g/L | 11.26 g/L | 15.2 g/L | 7.35 g/L | 1.53 | 710 L/kg $VS_{destroyed}$ |
| | HRT 3 days | 18.91 g/L | 12.48 g/L | 15.0 g/L | 8.62 g/L | 1.45 | 710 L/kg $VS_{destroyed}$ |
| | HRT 2 days | 18.75 g/L | 13.54 g/L | 15.0 g/L | 9.80 g/L | 1.38 | 600 L/kg $VS_{destroyed}$ |
| Griffin *et al.* (1997) | Mesophilic | | 48% removal | | 53% removal | 0.91 | 54% |
| | Thermophilic | | 53% removal | | 54% removal | 0.98 | 59% |
| Oleszkiewicz and Poggi-Varaldo (1997) | Trial 1 | 30% | 27.00% | 28% | 16.00% | 1.69 | 302 L/kg $VS_{fed}$ |
| | Trial 2 | 29.70% | 26.10% | 27.80% | 14% | 1.86 | 199 L/kg $VS_{fed}$ |
| | Trial 3 | 23% | 23% | 29% | 13% | 1.77 | 273 L/kg $VS_{fed}$ |
| Jokela *et al.* (2005) | Office Paper | | 73% removal | | 88% removal | 0.83 | 340 $m^3$/total $VS_{added}$ |

## DISCUSSION

Using the Tables 1, 2, and 3 as summaries of the data gathered from several papers some conclusions can be drawn regarding the effects of ammonia-nitrogen, volatile fatty acids, and total solids and volatile solids.

In the majority of the studies, the lower the final ammonia-nitrogen was, the lower the methane production. There were two exceptions, showing that the lowest ammonia-nitrogen corresponded to the highest methane production. The differences in methane production for the trial with the lowest ammonia-nitrogen and the trial with the highest methane varied by quite a bit. In the study by Tada *et al.* (2004), the difference in methane production was by two-fold. However, the paper by Misi and Forster (2001) did not see such a wide range of methane production.

The volatile fatty acids data compared similarly to the results of the ammonia-nitrogen. The lower the final concentration of VFA was, the lower the methane production. The differences between the methane produced by the trial with the lowest VFA and the trial with the highest methane varied by only a small amount.

Due to the large differences of reported data for the total solids and volatile solids, comparisons can be made only due to the ratio of the final TS/VS. This ratio allows the numbers to be unitless and gives an opportunity for greater interpretation of the result. Although there was also some difficulty obtaining similar units for the production of methane, the values attained are close to values from other studies as drawn from Table 1 and Table 2. From the data, it can be noted that in most cases, the higher the ratio of TS/VS the higher the methane production. This was clearly not the case for one study, done by Oleszkiewicz and Poggi-Varaldo (1997), which followed the direct opposite of this trend. As that study did not control the HRT and the temperature during data collection, it can be concluded that this had some affect on the backwards trend of TS/VS to methane production. Also that study was geared towards examining the effects of high-solids waste, with beginning total solids ranging from 30-35%. That is quite a bit higher than the other studies that used less than 10% TS in the digester.

The main concern with looking at the collect data in this comparative fashion is the variety of other changes in the different studies. For example, the study by Parawira *et al.* (2005) used two different types of digesters while the study by Misi and Forster (2001) used only one type of digester and a single batch of waste. The other studies varied such parameters as substrates, HRT, pH, and temperature. Despite this, it is maintained that the results achieved from these different studies bring to light some good beginnings of data, and relatively novel conclusions.

## CONCLUSION

During anaerobic digestion the methane produced can be used for energy purposes. After anaerobic digestion, the biosolids can be applied to the land as fertilizer or soil conditioners. This paper examined three parameters of the biosolids the concentration of ammonia-nitrogen, volatile fatty acids, and total solids and volatile solids. All of these affect the soil, water, and air in different ways and need to be considered if a waste is to be used as a fertilizer.

The data presented in this paper is by no means all-encompassing. Due to the different units and variable of HRT and temperatures during the studies, add many variables that were not fully examined in this paper. If the waste products of anaerobic digestion are to be applied on the land, more research should be done using different substrates that focuses directly on the change in ammonia-nitrogen, volatile fatty acids, and total solids and volatile solids. These studies would provide more concrete data as they could keep temperature, HRT, pH, etc. as constants and thus decreasing the uncertainty of results. Future studies are especially needed with the up-coming restrictions on the ammonia-nitrogen limits for land application.

## REFERENCES

"Anaerobic Digestion". (2005) <www.wikipedia.org> Accessed Nov. 2005.

Bouallagui, H.; Touhami, Y.; Ben Cheikh, R.; and Hamdi, M. (2005) Bioreactor Performance in Anaerobic Digestion of Fruit and Vegetable Wastes. *Process Biochemistry*, **40**, 989.

Callaghan, F.J.; Wase, D.A.J.; Thayanithy, K.; and Forster C.F. (2002) Continuous Co-Digestion of Cattle Slurry with Fruit and Vegetable Wastes and Chicken Manure. *Biomass and Bioenergy*, **27**, 71.

Carucci, G.; Carrasco, F.; Trifoni, K.; Majone, M.; and Beccari, M. (2005) Anaerobic Digestion of Food Industry Wastes: Effect of Codigestion on Methane Yield. *Journal of Environmental Engineering,* ASCE, **2005**, 1037.

Commission of Energy. (2005) <www.eurounion.org> Accessed Nov. 2005.

El-Mashad, Hamed M.; Zeeman, Grietje; van Loon, Wilko K.P.; Bot, Gerard P.A.; and Lettinga, Gatze. (2004) Effect of Temperature and Temperature Fluctuation on Thermophilic Anaerobic Digestion of Cattle Manure. *Bioresource Technology*, **95**, 191.

Han, Sun-Kee; Kim, Sang-Hyoun; and Shin, Hang-Sik. (2005) UASB Treatment of Wastewater with VFA and Alcohol Generated During Hydrogen Fermentation of Food Waste. *Process Biochemistry*, **30**, 2897.

Harris, Paul. (2005) "Waste Digester Design". <www.ce.ufl.edu/activities/waste/wddstu.html> Accessed Nov. 2005.

Hill, D.T. and Bolte, J.P. (2000) Methane production from the Low Solid Concentration Liquid Swine Waste Using Conventional Anaerobic Fermentation. *Bioresource Technology,* **74**, 241.

Karim, Khursheed; Klasson, K. Thomas; Hoffmann, Rebecca; Drescher, Sadie R.; DePaoli, David W.; and Al-Dahhan, M.H. (2005) Anaerobic Digestion of Animal Waste: Effect of Mixing. *Bioresource Technology*, **96**, 1607.

Lallai, A.; Mura, G.; and Onnis, N. (2001) The Effects of Certain Antibiotics on Biogas Production in the Anaerobic Digestion of Pig Waste Slurry. *Bioresource Technology*, **82**, 205.

Misi, S.N. and Forster, C.F. (2001) Batch Co-Digestion of Multi-Component Agro-Wastes. *Bioresource Technology*, **80**, 19.

Møllera, H.B.; Sommer, S.G.; and Ahring, B.K. (2004) Methane Productivity of Manure, Straw and Solid Fractions of Manure. *Biomass and Bioenergy*, **26**, 485.

Neves, L.; Oliveira, R.; and Alves, M.M. (2005) Anaerobic Co-Digestion of Coffee Waste and Sewage Sludge. *Waste Management*, article in press.

Oleszkiewicz, Jan A. and Poggi-Varaldo, Hector M. (1997). High-Solids Anaerobic Digestion of Mixed Municipal and Industrial Waste. *Journal of Environmental Engineering*, ASCE, **1997**, 1087.

Parawira, W.; Murto, M.; Read, J.S.; and Mattiasson, B. (2005) Profile of Hydrolases and Biogas Production During Two-Stage Mesophilic Anaerobic Digestion of Solid Potato Waste. *Process Biochemistry*, **40**, 2945.

Parawira, W.; Murto, M.; Zvauya, R.; and Mattiasson, B. (2004) Anaerobic Batch Digestion of Solid Potato Waste Alone and in Combination with Sugar Beet Leaves. *Renewable Energy*, **29**, 1811.

Ram, M. Sai; Signh, L.; Suryanarayana, M.V.S.; and Alam, S.I. (2000) Effect of Iron, Nickel, and Cobalt on Bacterial Activity and Dynamics during Anaerobic Oxidation of Organic Matter. *Water, Air, and Soil Pollution* (Netherlands), **117**, 305.

Ramasamy, E.V. and Abbasi, S.A. (2000) Energy Recovery from Dairy Waste-Waters: Impacts of Biofilm Support Systmes on Anaerobic CST Reactors. *Applied Energy*, **65**, 91.

"Renewable Energy for Europe". (2004) <http://www.kristianstad.se/upload/Sprak/dokument/environment_eng.pdf> Accessed Nov. 2005.

Schmidt, David. (2005) "Anaerobic Digestion Overview" <www.mnproject.org/presentations/Schmidt/Anaerobicdigestion101.pdf> Accessed Nov. 2005.

Tada, Chika; Yang, Yingnan; Hanaoka, Toshiaki; Sonoda, Akinari; Ooi, Kenta; and Sawayama, Shigeki. (2005) Effect of Natural Zeolite on Methane Production for Anaerobic Digestion of Ammonium Rich Organic Sludge. *Bioresource Technology*, **96**, 459.

Wang, J.Y.; Zhang, H.; Stabnikova, O.; and Tay, J.H. (2005) Comparison of Lab-Scale and Pilot-scale Hybrid Anaerobic Solid-liquid Systems Operated in Batch and Semi-continuous Modes. *Process Biochemistry*, article in press.

Wilkie, Ann C. (2003) Anaerobic Digestion of Flushed Dairy Manure. *Proceedings – Anaerobic Digester Technology Applications in Animal Agriculture – A National Summit*, from the Water Environment Federation. <http://www.epa.gov/agstar/pdf/wefjune2003.pdf> Accessed Nov. 2005.