CHARACTERIZATION OF FRUIT AND VEGETABLE WASTES FOR ENERGY PRODUCTION

Gary L. Hawkins, University of Georgia, Department of Biological and Agricultural Engineering, University of Georgia Tifton Campus, P.O. Box 748, Tifton, GA 31793-0748

Introduction

The Georgia Department of Agriculture (GADOA, 2006) reports that in 2004 production of five fruits and vegetables (cucumber, bell pepper, squash, tomato, watermelon) in Georgia amounted to 860 million pounds (390 million kg). The weight of fruit and vegetables listed above only accounts for that produce harvested and does not account for that produce remaining in the field after the market has eroded. This eroded market is associated with both the large producer working with major distributors or the small farmer growing mainly for local and regional farmers markets. From discussions with the environmental manager of one packing house, an estimate of the amount of fruits and vegetables that would be culled (thrown out) at the packing house would be 7%. This means that 60 million pounds (27 million kg) of fruit and vegetable waste would need to be discarded annually in Georgia. Based on interviews of two watermelon farmers, an equal amount of unharvested watermelons remain in the field after harvest has occurred for sale. Collection of fruit and vegetable waste by the principal investigator indicates that 39,000 pounds of tomatoes and 49,000 pounds of watermelons are left on each acre (Hawkins, 2006) after harvest has been completed. This will change from year to year based on market and growing season, therefore collections will continue so that a long term average can be acquired. In 2004, Georgia had 6000 acres of tomatoes and 30,000 acres of watermelons planted (GA DOA, 2006).

Typically waste material from packing houses would be dumped in low lying areas on a farm, placed in landfills, incorporated into compost piles or fed to animals. Disposal of these waste products in low lying areas has the potential to pollute nearby waterways. Disposal in landfills costs the producer, fills the landfill space sooner and adds water to the landfill, potentially adding to leachate quantities. Composting of this material provides some conversion to materials that can be used as a soil amendment, but the waste product is typically greater than 85% moisture (Hawkins, 2006; Viturtia, et al., 1989; Viswanath et al., 1992) and has a high sugar content which aids in bacterial biomass growth, but little humus formation. Feeding to animals does dispose of the waste, but the potential transport cost could be a limiting factor to disposal.

As this material decomposes in an environment void of oxygen, the predominate gas produced is methane and some carbon dioxide. According to Vieitez and Ghosh (1999), decomposition of each metric ton of solid waste could potentially release 50-110 m^3 of carbon dioxide and 90-140 m^3 of methane. The release of carbon dioxide can add to the increasing problem with greenhouse gasses, but methane is known to be 23 times worse as a greenhouse gas.

However, by controlling the decomposition process in systems called anaerobic digesters, the methane can be captured and used for alternative energy sources verses released to the atmosphere and adding to the greenhouse gas problems. Anaerobic digesters have been used in many industries and in many countries to convert organic compounds into methane. These include municipalities, animal operations, fruit and vegetable processing plants and local food markets (Athanasopoulos, et al., 1990; Colleran, et al., 1983; Dugba and Zhang, 1999). One industry that has had little study in the US, but some around the world is using culled fruit and vegetable waste from packing houses or produce remaining in the field as the feedstock for anaerobic digestion for the formation of methane.

Anaerobic systems are best optimized if the feed rate of organic material into the digester is as constant as possible. This steady flow of organic material into the anaerobic digestion optimizes the conversion of the sugars in the waste material or feedstock into intermediate anaerobic products and helps keep the system functioning properly. Therefore, the purpose of this research was to begin defining the physical and chemical characteristics of some of the fruits and vegetables grown in Georgia.

Objectives of Research

The objectives of this research are to;

1. Define the physical characteristics of three fruits and vegetables grown in Georgia, and
2. Define the chemical characteristics of three fruits and vegetables grown in Georgia.

Materials and Methods

Samples of three fruits and vegetables were collected from research plots located in the Tifton Vegetable Research Park on the UGA-Tifton campus and local vegetable fields. Each sample consisted of a minimum of 10 fruits and vegetables each. These samples were taken as a subsample from harvested plots and fields. Samples were immediately returned to the lab, weighted, sliced, chopped, and dried. The samples were chopped into small manageable pieces and then further chopped into small pieces with a standard kitchen food processor. Once chopped, three samples of the pulp material, approximately 30 ml, was placed in a weighting pan for drying and ashing. From this same chopped sample a portion was taken, blended in a standard kitchen blender and squeezed to get a liquid sample for determining the chemical properties of the fruit or vegetable (Figure 1).

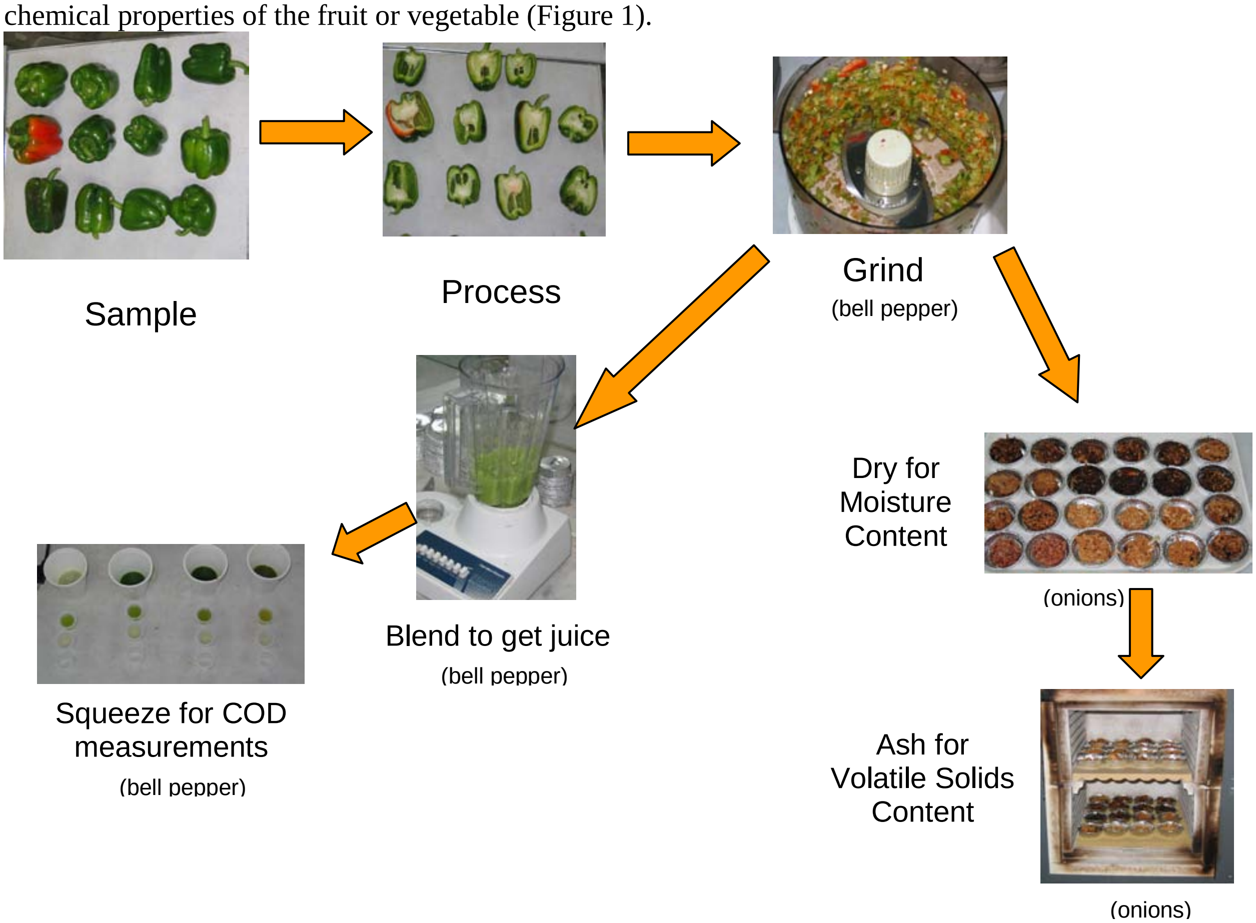

Figure 1. The process of taking a fruit or vegetable sample from a research plot or field, processing the sample through chopping, blending and squeezing to get solid and liquid materials to measure physical and chemical parameters.

The physical characteristics measured for each sample was percent moisture and percent volatile solids (VS). The samples were oven dried at 105^{o}C and ashed at 550^{o}C according to Standard procedures (APHA, 2005). The chemical characteristics measured for each sample was the chemical oxygen demand (COD). COD values for the samples were measured using the COD Test-N-Tube method (HACH Company, Loveland, CO) and are a measure of the amount of oxygen required to completely convert any organic compound into carbon dioxide and water. The COD measurement is also a means to characterize the strength of the liquid, in this case the tomato and bell pepper juice.. The VS and COD values are directly used in determining the amount of material that can be fed into an anaerobic digester on a daily basis.

Results and Discussion

The results shown in figures 2 and 3 are for three of the fruits and vegetables grown in Georgia. Others have been analyzed for physical and chemical characteristics and the results can be seen in Hawkins (2008a and 2008b).

The three bars shown on the graph are for total volatile solids (that amount of material that is converted to carbon dioxide when burned at 550^{o}C), percent VS in the total sample and percent moisture of the sample calculated after drying in a 105^{o}C oven. As can be seen in the graph, the VS content (blue bar/left most bar) for the tomatoes were slightly different numerically between years, but were not significantly different. Likewise, the VS content of the bell peppers were numerically different between years, but were not significantly different. Also, the VS content between the tomatoes and bell peppers were not significantly different between vegetables or years. The percent VS for the tomatoes and bell peppers were also not significantly different except for the 2007 tomatoes which were different from the 2006 tomatoes and both bell pepper years. These values are comparable to other research values (Carucci, et al., 2005; Bouallagui, et al., 2005). The percent moisture was significantly the same for the two bell pepper years and the 2007 tomatoes, but the 2006 tomatoes were different than the other three. As the data indicates there are differences in the VS, %VS and moisture from one growing season to another as well as there could be differences between fields. This data however, indicates that is the tomatoes and bell pepper were both being utilized as a feedstock for an anaerobic digester, they should be suitable to be co-fed at equal volumes. From figure 2, it can also be seen that the amount of VS in the broccoli is numerically and significantly higher than that of the bell pepper and the tomato. However, the %VS is significantly the same.

The measured chemical characteristic of two of the tested fruit and vegetables can be seen in Figure 3. The tomatoes and bell peppers were squeezed to get a juice fraction, but the broccoli was not squeezed, therefore there is no COD data available for that vegetable. As the data indicates, bell peppers have a COD or liquid strength approximately 9 times greater than that of tomatoes.

The data in figures 2 and 3 is useful in determining the amount of material that can be fed into an anaerobic digester. When looking at organic loading rates (OLR), the amount of material that can be fed to a reactor on a kilogram per liter of reactor per day basis is important to optimize the amount of conversion of organics to methane. In the literature, OLRs are usually given in terms of the VS or COD. Some values presented in the literature for fruit and vegetable waste are 3.6 - 6.4 kg VS $m^{-3}d^{-1}$ (Callaghan, et al., 2002; Bouallagui, et al., 2005; Viswanath, et al., 1992; Mata-Alvarez, et al., 1992) or 4 – 15 kg COD m^{-3} d^{-1} (Verrier, et al., 1983; Brondeau et al., 1982; Bouallagui, et al., 2004). This means that the anaerobic digester can receive 3.6 to 6.4 kg of volatile solids or 4 to 15 kg of COD per cubic meter of digester per day.

The values shown in figures 2 and 3 are good starting points to design anaerobic digestion systems, but other important information is needed to optimize the conversion of fruit and vegetable waste to methane. Additional information needed to optimize the conversion process is the nitrogen and carbon amounts to insure we have the proper N:C ratio to optimize biomass growth. Average volumes of materials produced daily and the frequency of that material production. All of this information is vital in designing a system to optimize methane output and reactor size. Lab scale digesters have been started on the UGA-Tifton campus and are being used to verify and determine optimal feed rates and methane outputs from different fruit and vegetable waste. When sufficient data is available, the values will be used to design pilot scale systems and be used to secure funding to design an operating plant for converting the waste to methane.

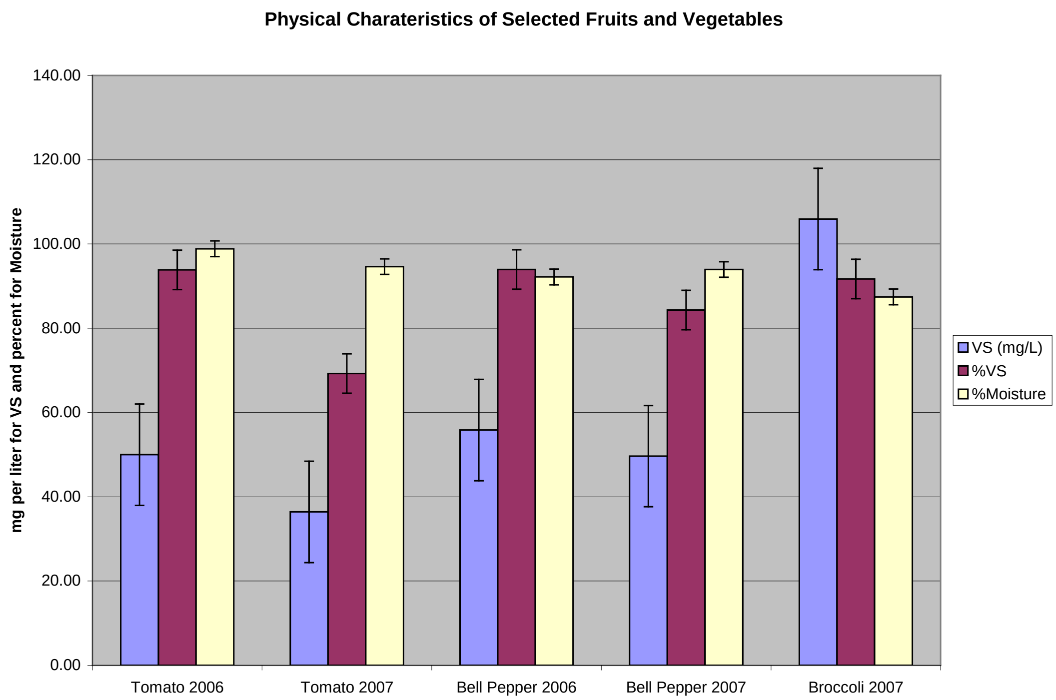

Figure 2. Data collected for the volatile solids, percent volatile solids and percent moisture of vegetables tested.

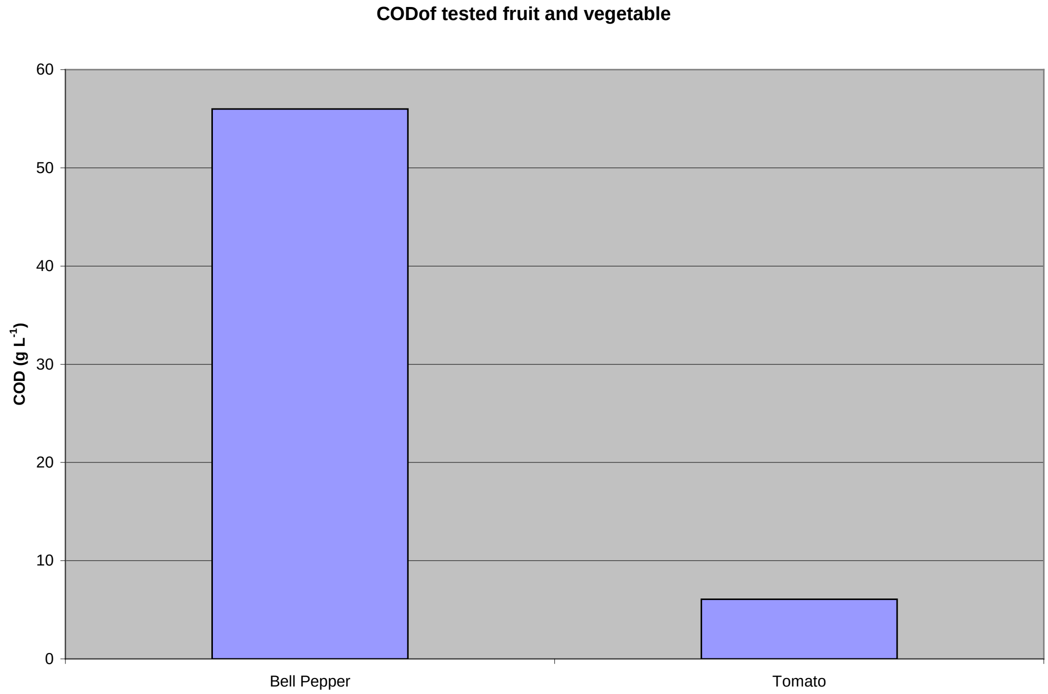

Figure 3. Chemical oxygen demand (COD) values for the tomatoes and bell pepper tested.

Conclusion

Determining the values for the physical and chemical characteristics of fruit and vegetable waste is the initial process in designing an anaerobic digestion system for the conversion of fruit and vegetable waste to energy. As can been seen from the data presented here, the VS contents of two of the three fruits and vegetables are significantly the same which means when designing an AD system based on VS we can load or feed the digesters at the same rate. Since the broccoli has a VS value double that of the tomatoes and bell pepper, a feed rate half that of the other two would be required. If however, we only concentrate on the liquid fraction as a feedstock for the AD system, the data indicates that bell pepper juice would have to be fed at a rate 9 times less than that of tomato.

Overall, when designing an anaerobic digestion system, the characteristics of the feedstock is important in that the microbial population in the digesters can only decompose and convert sugars, carbohydrates and proteins into methane at a given rate. Analyzing the physical and chemical characteristics of fruit and vegetable waste allows the anaerobic digestion manager to best optimize the feed rate of waste into the digesters and therefore optimize the output of methane.

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