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DEVELOPMENT OF AN ANAEROBIC TREATMENT SCREENING
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ERIN HENDERSON SZCZEGIELNIAK

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Steven I. Safferman
Major Professor's Signature

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DEVELOPMENT OF AN ANAEROBIC TREATMENT SCREENING PROTOCOL FOR FRUIT AND VEGETABLE PROCESSING WASTEWATER

By

Erin Henderson Szczegielniak

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ABSTRACT

DEVELOPMENT OF AN ANAEROBIC TREATMENT SCREENING PROTOCOL FOR FRUIT AND VEGETABLE PROCESSING WASTEWATER

By

Erin Henderson Szczegielniak

Fruit and vegetable processors commonly produce large volumes of high strength wastewater that may be inadequately treated by land application. Anaerobic digestion reduces or eliminates the need for soil treatment and produces biogas which has the potential to provide the processor with a renewable energy resource. A novel screening protocol was developed to help food processors determine the economic feasibility of instituting an anaerobic digester. The protocol assesses a processing waste stream's pretreatment requirement (e.g. pH buffering or nutrient limitations), biogas potential using an anaerobic respirometer, and biogas quality (% CH_4). Processor needs, wastewater parameters and respirometer results are considered in tandem to conclude whether the processor should further pursue anaerobic treatment in a pilot-scale study. The protocol was tested under three conditions including one in replicate, one blended substrate and one failed condition, with distinguishing results indicating appropriate or inappropriate substrates for anaerobic treatment. For each case study, the substrates were characterized by common wastewater parameters and tested in an anaerobic respirometer. Gas samples from the respirometer flasks' headspace were collected and analyzed in a gas chromatograph for methane and carbon dioxide.

This work is dedicated to the food processors of Michigan.
Here's to a brighter, cleaner future.

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KEY TO ABBREVIATIONS AND ACRONYMS

BMP	biological methane potential
COD	chemical oxygen demand
HRT	hydraulic retention time
MDEQ	Michigan Department of Environmental Quality
Rep.	replicate
SCOD	soluble chemical oxygen demand
TMP	theoretical methane potential
TS	total solids
VFA	volatile fatty acids
VS	volatile solids

CHAPTER 1: INTRODUCTION

Fruit and vegetable processors face technical challenges and potential costs in treating the large volumes of high strength wastewater resulting from production. All processors face rising fuel costs. Processors with access to a municipal treatment plant must often meet volume and quality restrictions and pay a base amount for flow and surcharges for high solids, biochemical oxygen demand and nutrients. Often a pretreatment system is needed prior to discharge to the sewer. Processors in rural areas commonly employ lagoon systems and land application which incorporates soil treatment. While minimally regulated in the past, land application may soon face more stringent regulations.

One possible solution is anaerobic digestion which reduces or eliminates the need for municipal or soil treatment and would provide the processor with an energy resource from the biogas. Anaerobic biogas consists primarily of methane and thus can be burned as natural gas or transformed into electricity.

While anaerobic digestion offers an attractive solution, not all waste streams are appropriate for anaerobic treatment. If the wastewater has a significant concentration of sanitizers, a non-neutral pH or a nutrient deficiency, then biodegradation and methane production will be inhibited. The high capital investment of such a treatment system necessitates preliminary screening to ensure that the waste is anaerobically biodegradable.

Anaerobic biodegradability is typically reported in terms of percent chemical oxygen demand (COD) removed. More advanced testing to determine the biogas potential is often desired, which can be achieved using anaerobic respirometry. A respirometer study measures the individual gas production from multiple reaction flasks.

Thus far, respirometers have commonly been used to study aerobic treatment methods, a trend which mirrors the predominance of conventional aerobic treatment methods in the wastewater treatment field. As anaerobic digestion and its advantages are becoming better understood and appreciated, the respirometer has been utilized for anaerobic studies in municipal wastewater applications. Conversely, many anaerobic studies have focused on food processing wastewater over the past two decades, but none have been found to use respirometers.

The first objective was to develop a protocol to pre-screen fruit and vegetable processing waste streams for anaerobic treatment by determining the biogas potential using an anaerobic respirometer. Employing anaerobic respirometry provides a cost effective and efficient means for a processor to investigate anaerobic treatment options prior to investing significant time and money in a pilot-scale test or a full-scale system. The purpose of the protocol was to provide a step by step methodology for the determination of anaerobic biodegradability. This required general guidelines to apply this method to any waste stream, the parameters of which could fall within wide ranges. These parameters affect how long the respirometer trial must run and the net biogas produced.

The second objective was to test the protocol under three conditions: an ideal substrate, a low-COD substrate and a blended substrate. ‘Ideal’ and ‘low-COD’ substrates were defined as suggested by supporting literature. A fourth case of interest involved a failed condition, which happened to be incorporated in the blended substrate case. Observing a failed substrate was important in demonstrating that the respirometer results did not produce false positives. Testing these conditions served to develop and check the utility of the protocol, which was then revised based on these test results. The purpose of this research was not to compare specific waste streams.

As the protocol employs a small-scale apparatus, its results are not directly representative of a full-scale operation nor do they guarantee full-scale success. Flasks smaller than a liter, such as the respirometer uses, do not accurately reflect the mixing effects in a full-scale digester. The purpose of the protocol is to verify if a pilot-scale study is a worthy investment.

CHAPTER 2: LITERATURE REVIEW

2.1 Anaerobic Treatment Applications

Anaerobic digestion is most widely established as a waste treatment method in Western Europe (Angelidaki et al., 1999). Regulations there require strict abatement of greenhouse gases including methane and carbon dioxide (Carucci et al., 2005). As a treatment technology, anaerobic digestion is unique in that it both reduces waste and produces an energy resource in the biogas. Potential anaerobic feed substrates include manure (Al-Masri, 2001; Demirer and Chen, 2005), crop residues (Stewart et al., 1984; Weiland, 1993), organic municipal solid waste (i.e. solid food wastes) from restaurants or markets (Bouallagui et al., 2003; Han et al., 2005; Xu et al., 2002; Kiely et al., 1996), and wastewater from food processing plants (Tekin and Dalgic, 2000; Alvarez et al., 2005; Lepisto and Rintala, 1997; Viswanath et al., 1992).

2.2 Microbiology

There are four processing steps defined in anaerobic digestion, each attributed to different trophic groups. The first three steps are hydrolysis, acidogenesis, and acetogenesis, which are each performed by different bacterial groups. The final step is methanogenesis, performed by a type of archaea aptly termed methanogens (Bouallagui et al., 2004a).

In studying anaerobic digestion it is important to recognize that methanogens are archaea and still often mislabeled as bacteria. Archaea make up a domain separate from bacteria and eukarya, and include methanogens, thermophiles, and halophiles (Schiraldi et al., 2002). Woese and Fox (1977) distinguished the domain by noting that archaea evince stark biochemical and genetic differences from bacteria.

Anaerobic bacteria have different optimal pH and nutrient levels from methanogens and exhibit different growth kinetics and stress responses (Bouallagui et al., 2004a). Methanogens are generally more sensitive than bacteria to environmental fluctuations. It is common for anaerobic digesters to manifest an unstable methanogen population: methane production may fluctuate significantly while bacterial volatile fatty acid (VFA) productions remain consistent (Bouallagui et al., 2005). The rate-controlling step is often acetogenisis though, as evidenced by VFA accumulation (Speece, 1996; Bouallagui et al., 2005).

Optimal environmental needs include pH and alkalinity, temperature, macronutrients (C/N/P), bioavailable micronutrients, and a lack of toxicity (Speece, 1996). Adequate conditions for all parameters must exist for a digester to flourish, as discussed below.

2.3 pH and Alkalinity

Optimal alkalinity and pH, between 6.5 and 8.2 (Speece, 1996), are critical for stable methanogensis, and yet confounded by the proceeding process steps that produce CO_2 and other acids. If acetogens are slowed by environmental stressors, then acids go unprocessed and pH will quickly drop, inhibiting methanogenesis entirely (Bouallagui et al., 2005; Speece, 1996). To counter this acidifying effect, alkalinity in the digester must be balanced with VFA levels relative to organic loading rate and hydraulic retention times (HRT) (Borja et al., 2004). A two-stage digester system, with separate sections for acid and methane formation, was found to quell rising acid levels (Bouallagui et al., 2005). Biodegradation can also be limited by high pH though (Penaud et al. 1999), as ammonia is un-ionized above a pH of 8 and thus toxic (Speece, 1996).

2.4 Temperature

Anaerobic digestion can occur in three distinct temperature ranges: psychrophilic at 15°C to 25°C, mesophilic at 30°C to 37°C, and thermophilic at 50°C to 65°C (Bouallagui et al., 2004b; Speece, 1996). It should be noted that thermophilic digestion is unrelated to the thermophile archaea that inhabit more extreme locales such as geysers and ocean heat vents. A distinct transition region between mesophilic and thermophilic digestion is evinced around 45°C where methane production notably decreases (Converti et al., 1999; Speece, 1996). Methanogens are also sensitive to abrupt temperature change (Bouallagui et al., 2004b). A 5°C drop resulted in a 34% decrease in methane production (Speece, 1996).

Thermophilic biomass has a higher metabolic rate than mesophilic and thus higher gas production (Speece, 1996; Converti et al., 1999) and protein assimilation (Speece, 1996). Thermophilic systems also exhibit greater pathogen elimination (Bouallagui et al., 2004b; Duran, 2006). Methanogens exhibited improved activity with higher temperatures (Converti et al., 1999). The optimal temperature for acetoclastic methanogens was found to be 56°C to 59°C (Speece, 1996).

Thermophilic digestion requires disproportionately higher metal nutrients (Speece, 2006) and has a significantly slower growth rate than mesophiles and consequently a longer start-up period (Speece, 1996). A two-stage system with thermophlic and mesophilic in series utilized the advantages of both (Bouallagui et al., 2005).

A digester's temperature range is often selected to compliment the climatic region, as to avoid excessive heating demands (Bouallagui et al., 2004b). It follows then that as Europe is the prevailing region in anaerobic research and development and of a temperate clime, mesophilic systems are most commonly studied and pursued (Borja et al., 2004; Penaud et al., 1999; Al-Masri, 2001; Bouallagui et al., 2003). An underlying reason may also be that acetogens and methanogens are equally active at a mid temperature range (Speece, 1996); acetogen activity dominates at lower temperatures where methanogens are more active a higher temperatures.

2.5 Nutrient Availability

Methanogenesis is very sensitive to nutrient availability. Basic macronutrients and a library of micronutrients must be properly allotted and biologically available (Speece, 1996). Like most metabolic processes, anaerobic digestion requires an adequate C:N:P ratio, where carbon is often accounted for in terms of COD. One source considered fruit and vegetable waste to be balanced with a COD/N/P of 100/4.3/0.9 (Bouallagui et al., 2004b). Nitrogen or phosphorus deficiency may be expressed by VFA accumulation (Speece, 1996). Ammonium can be used as an indicator of digester performance (Carucci et al., 2005; Speece, 1996).

Micronutrient availability can play a pivotal role in anaerobic digestion. When a food waste lacking in trace metals was co-digested with municipal sludge abundant in iron, manganese, copper and zinc, significantly more methane was produced than from food waste alone (Carucci et al., 2005). Low methane production initially attributed to toxicity may often be amended by trace metal addition, particularly iron, cobalt and nickel (Speece, 1996). To prevent such limiting conditions in batch digesters and bench-scale studies, researchers commonly provide bulk nutrient solutions with a host of trace metals (Owen et al., 1979; Shelton and Tiedje, 1984; DiStefano and Ambulkar, 2006; Aquino and Stuckey, 2007). Iron, cobalt, nickel, zinc, copper, manganese, molybdenum, selenium, tungsten and boron have been shown to stimulate methanogenesis (Speece, 1996; Speece, 2006).

Among required nutrients, sulfide is especially noteworthy. While microbes require sulfide, it readily precipitates with various trace metals (especially iron), rendering all biologically unavailable (Speece, 1996; Isa et al., 1986). Sulfur also plays a role in the multifaceted competition between methanogens and sulfate reducing bacteria, which produce hydrogen sulfide in lieu of methane (Speece, 1996). Hydrogen sulfide gas is toxic to both anaerobes and humans. Sulfate and free sulfide are recognized as methanogen inhibitors at higher concentrations (Isa et al., 1986).

2.6 Toxicity

Anaerobic digestion can be hindered by certain compounds. At high concentrations, potassium and other salts can interrupt cell function (Carucci et al.; 2005; Speece, 1996). Sodium chloride was found to inhibit methanogenic activity (Dolfing and Bloemen, 1985). It was shown however, that in adding sodium hydroxide, the hydroxide anions caused the negative effect, not the sodium cations (Penaud et al., 1999). Surfactants were shown to cause greater inhibition of anaerobic treatment than aerobic treatment (Mohan et al., 2006). As mentioned in section 2.3, ammonia is un-ionized above pH 8 and is toxic to anaerobes. Acetogens are particularly sensitive, and concentrations above 3000 mg/L NH_4-N are toxic regardless of pH (Calli et al., 2005). While not necessarily 'toxic', increased total solids loading have a direct correlation with methanogen inhibition (Viswanath et al., 1992; Carucci et al., 2005; Tekin and Dalgic, 2000). General toxicity can be determined by an Anaerobic Toxicity Assay, in which gas production rates are depressed despite an abundance of acetate (Owen et al., 1979; Speece, 1996).

Long-chain fatty acids (LCFAs) and polyphenols are natural antimicrobial compounds. In multiple studies of different phenol-rich substrates, anaerobic digestion was drastically inhibited unless some form of pre-treatment was employed, such as ozonation (Alvarez et al., 2005), fungal treatment (Dhouib et al., 2006), or electro Fenton reaction (Khoufi et al., 2006). Adding sulfate during treatment can also improve phenol biodegradability (Speece, 1996; Isa et al., 1986), though the negative affects of sulfate must then be abated. It is important to note that while a microbe population may express inhibition upon initial exposure to a compound, anaerobes have a strong ability to acclimate (Speece, 1996). Acclimation to LCFAs could not be achieved and the inhibiting affect was irreversible (Angelidaki and Ahring, 1992).

2.7 Estimating Biogas Production

Simple anaerobic digestibility is often reported in terms of percent COD removal. Further testing is often desired to determine the biological methane potential, reported as volume methane produced per unit COD. Batch tests are commonly conducted using some variation of the Owen serum bottle method (Owen et al., 1979; Demirer et al., 2000; Han et al., 2005; Shelton and Tiedje, 1984). Based on preliminary batch test results, studies are often expanded to a semi-continuous bench scale reactor (Carucci et al., 2005; Hwang and Cheng, 1991). There are respirometers available for anaerobic applications. In anaerobic mode, a respirometer measures the individual gas production from multiple flasks, each approximately 500 mL in volume (Mohan et al., 2006). This combines the benefit of test controls and replicates from the serum bottle methods with the continuous gas monitoring of bench scale reactors (DiStefano and Ambulkar, 2006). In a hydrogen production study, the anaerobic respirometer produced 43% more gas than the Owen serum bottle method (Logan et al., 2002).

Many studies use synthetic substrates to observe the affects of specific parameters on anaerobic digestion (Converti et al., 1999; Conklin et al., 2006); Isa et al., 1986; Fitzgerald, 1996). However, to study wastewater biodegradability in the lab, substrate must be imported from the original processing waste stream because processing wastewaters often include a conglomeration of food wastes, disinfectants, anti-scaling and other chemicals, the interactions of which cannot be synthetically replicated.

2.8 Digester Start-up, Operation and Acclimation

Anaerobes have a relatively slow growth rate compared to their aerobic counterparts. Organic substrate must be processed through several steps before reaching simple carbon compounds appropriate for methanogenesis. Thus, a reactor of any size may require several weeks of acclimation before significant methane production is observed. A two-liter lab reactor digesting pig slurry produced minimal biogas for the first 25 days of testing (Kiely et al., 1997). Start-up time is greatly improved when the reactor is seeded with adequate inoculate from an acclimated seed source (Totzke, 2006).

Different methanogen species express distinct responses to environmental stimuli and stressors. Hourly versus daily feeding schedules were shown to select for methanogens with low and high growth rates, respectively

(Conklin et al., 2006). The microbes with a higher growth rate made for a more stable digester, responding better to peak loads and feed shortages.

Biogas production is also influenced by organic loading, total solids and hydraulic retention time (HRT) (Viswanath et al., 1992; Tekin and Dalgic, 2000). HRT is of greater concern for a substrate with a high non-soluble fraction (Tekin and Dalgic, 2000). Switching feedstock between different fruit wastes evinced little effect on biogas production (Viswanath et al., 1992). This is significant for food processing applications as plants often switch seasonal commodities throughout the year. Table 2.1 includes a brief comparison of various sized reactors and feed sources and their subsequent methane production.

Table 2.1 Biogas Production from Various Commodities and Reactor Types

Reference	Commodity	Reactor Type/ Size	Temperature	Biogas Production	Methane fraction
Bouallagui et al. 2004b	Raw fruit & vegetable waste (shredded)	Tubular/ 18L	Psychrophilic Mesophilic Thermophilic	0.64-1.05 L/L/d 0.83-2.34 L/L/d 1.7 -3.17 L/L/d	56-58% 54-65 % 58-62%
Alvarez et al. 2005	Cherry stillage	Sequencing Batch Reactor / 1.8 L	Low mesophilic (30°C)		58-71%
Stewart et al. 1984	Bananas (fruit and stem) Potatoes (peelings, rejects) Oats	Continuous/ 20 L	Mesophilic	497 L/kg TS 350-410 L/kg TS 227-257 L/kg TS	53% 44-50% 51-54%
Yacob et al. 2006	Palm oil mill effluent	Closed digester/ 500 m^3	High mesophilic (37-42°C)	650-1000 kg/d	
Tekin and Dalgic 2000	Olive pomace	Semi-continuous/ 1 L	Mesophilic	0.39-0.69 L/L/d	79.5-84%
Viswanath et al. 1992	Sequential feedings: mango, orange, pineapple, tomato processing, jackfruit and banana waste	Semi-continuous/ 45 L	Low mesophilic (30°C)	0.61-1.96 L/L/d	22-61.2%
Lepisto and Rintala 1997	Carrot processing wastewater. Potato and swede processing wastewater	UASB/ 2-3 L	Thermophilic (55°C)	7.3 L/L/d (315 cm^3/g COD) 347 cm^3/g COD	49% (carrots)

2.9 Biogas Products

Methane and carbon dioxide are the main constituents of anaerobic biogas. The methane fraction can range from 40 to 85% depending on methanogen vitality, substrate quality and reactor type (Alvarez et al., 2005; Stewart et al., 1984; Tekin and Dalgic, 2000; Yacob et al., 2006). A large percentage of the carbon dioxide remains in solution (Shelton and Tiedje, 1984). Being mostly methane, biogas can be collected and burned, like natural gas, for thermal or electric energy. In Denmark, community digesters produce both heat for local farms and electricity to the power grid (Angelidaki et al., 1999). Several engine types are adapted to run on biogas, and emerging technology in high-temperature fuel cells can convert and store energy from biogas (Bove and Lunghi, 2006; Sorge, 2006). The anaerobic digestion process can also be manipulated to produce a higher percentage of hydrogen gas, a sought-after resource for fuel cells (Han et al., 2005; Logan et al., 2002).

There are also minor gas constituents which can be troublesome for certain applications. Biogas often includes a small fraction of hydrogen sulfide produced from sulfate-reducing bacteria (Speece, 1996). The specific percent fraction depends on the substrate components. Digestion of citric acid factory wastewater with 600 mg/L sulfate resulted in the biogas having 4% H_2S (Isa et al., 1986). Internal combustion engines are especially sensitive to hydrogen sulfide impurities (Speece, 1996) which can be expensive to purge (Isa et al., 1986).

2.10 Economic and Environmental Considerations

There are several economic considerations in choosing anaerobic treatment. While primary attention goes to methane as an energy source, those with experience in the field have found equal or greater benefit in the stabilized sludge end product (Tekin and Dalgic, 2000). There is also the opportunity to apply for carbon credits through such organizations as the Chicago Climate Exchange, for actively reducing methane and carbon dioxide emissions (Jensen, 2006).

There are various operating costs associated with an anaerobic digester. If the influent substrate has a low pH or alkalinity, an alkalinity source must be metered in to support a neutral pH. To maintain digester stability, it is necessary to extensively monitor various parameters. There has been recent research to develop infrared monitoring equipment to measure VFA, COD, alkalinity, sulfate and nitrogen in-line to limit the over-sizing of digesters and lower capital and operating costs (Spanjers et al. 2006). There had been some trouble of the monitoring equipment clogging with higher solids content though.

2.11 Advantages and Disadvantages

Anaerobic treatment allows for higher organic loading rates and requires lower nutrient levels than traditional aerobic treatment (Speece, 1996). There is no aeration required. While an anaerobic digester requires heating to maintain a mesophilic (or thermophilic) environment, this can often be met by reapplying 25% of the biogas as a heat source. Overall, anaerobic treatment can provide an energy resource while reducing a waste product. Due to the anaerobe's low growth kinetics, an anaerobic reactor can remain viable in a dormant state during periods of low flow or plant shut-down.

There are disadvantages to anaerobic wastewater treatment. It does not achieve significant nutrient treatment such as denitrification or phosphorus removal (Speece, 1996). If effluent discharge regulations require lower limits than can be met by anaerobic treatment, secondary or tertiary treatment such as aerobic polishing or phosphorus treatment would need to be considered. While a low growth rate can provide some advantages, it also equates to a slow start-up period and arduous recoveries from organic overloading or biomass washout.

CHAPTER 3: MATERIALS AND METHODS

3.1 Overview

Development of the screening protocol required a correlation between the conclusions drawn from the substrate characterization results and the respirometer results. Testing consisted of collecting and analyzing wastewater samples from various fruit and vegetable processing plants, and digesting the samples in an anaerobic respriometer. Respirometry tests included the analysis of gas samples from the headspace to verify significant methane production.

The substrates were characterized based on parameters of known relevance to anaerobic digestion. Respirometry testing was conducted at 35°C based on full-scale operating norms in the region. Quality assurance and quality control was observed in all aspects by the use (as applicable) of field duplicates, lab duplicates, standards, blanks and controls.

3.2 Substrate Sources

Wastewater was sampled from three fruit and vegetable processing plants. Coincidentally, all three plants were processing only fruit at the respective times at which wastewater was sampled. At the time of sampling, plant A was producing apple juice and dried cherries; plant B was processing apple slices; plant C was processing whole cherries. The subsequent studies of each sample are referred to as Case A, B and C, respectively. Two respirometer trials were conducted with sample B, denoted Case B-1 and B-2. In Case C, liquid manure was sampled from a local dairy farm for a blended substrate of manure and wastewater. Manure was collected following a cyclone sand-manure separator. The substrate constituents for Case C were analyzed separately and blended later based on these results. Bulk samples for respirometer testing were stored at 4°C until the respirometer was available to set up.

3.3 Substrate Characterization

Several parameters were tested, of which pH, COD, soluble COD (SCOD), total solids, volatile solids and total phosphorus were tested in-house at Michigan State University. Ammonia, nitrate + nitrite, TKN, sulfide and sulfate testing was conducted by a commercial laboratory, A&L Labs (Fort Wayne, IN). Immediately after being collected, these samples were packed on ice and shipped overnight to A&L Labs. Samples for COD, SCOD and total phosphorus were collected in glass containers, adjusted with sulfuric acid to a pH <2, stored at 4°C and analyzed within 28 days. Samples for pH, total and volatile solids were stored at 4°C and analyzed within seven days.

The pH was measured by a pH meter (accumet Excel XL60, Fisher Scientific) and electrode (accuCap, Fisher Scientific). COD was determined according to USEPA approved Hach Method 8000 (0 to 1500 mg COD/L) (Hach Company, Loveland, Col.). Total phosphorus was determined according to USEPA accepted Hach Method 8190 (Hach Company). TKN and nitrate plus nitrite were determined according to EPA methods 351.3 and 353.2, respectively. Sulfide was determined according to EPA method 376.2. Wastewater samples were analyzed for ammonia according to EPA method 350.2, and digested according to method SW846-3010A and then analyzed for sulfate according to EPA method 200.7. The liquid manure was analyzed for ammonia according to method SM(20th)-4500-NH3B,C. Sulfate was determined according to EPA method 375.4.

3.4 Anaerobic Repirometery

Respirometer testing was conducted with an AER 200 model (Challenge Technology, Springdale, Ark.) in anaerobic mode. The system consisted of eight nominal 500 mL reaction flasks maintained at 35°C in a constant temperature water bath and mixed via magnetic stir plate at approximately 100 rpm. Gas production resulted in a slight pressure buildup and dissipated in discrete bubbles, measured through calibrated flow measuring cells. A computer processed and stored the data, calculating the gas production rate and cumulative volume for each individual flask.

To minimize any lag in degradation due to microbial acclimation, seed was collected from a bench-scale reactor actively digesting ethanol processing byproducts. Both pH and COD were analyzed at the time of sample collection and, if stored, again at the time the respirometer set up, as these parameters may change in unpreserved samples during storage.

Several studies with nutrient solutions were considered (Owen et al., 1979; ASTM E, 1996; Shelton and Tiedje, 1984; DiStefano and Ambulkar, 2006;

Aquino and Stuckey, 2007). Shelton and Tiedje (1984) offered an improvement on the proposed ASTM standard and a detailed methodology that minimized precipitation. Though intended for serum bottle tests, this nutrient solution was similar to mediums described in respirometer literature (DiStefano and Ambulkar, 2006; Logan et al., 2002; Mohan et al., 2006).

Measured amounts of microbial seed, nutrient solution and wastewater substrate were added to multiple reaction flasks. Contents were stirred and maintained at a constant 35°C via a water bath. When filled to the lip of the bottle, nominal 500 mL Wheaton reaction flasks hold approximately 715 mL. Following the respirometer manufacturer's recommendations, a 10% headspace was allowed with a working volume of 650 mL. A 4:1 ratio of nutrient solution to seed as described by Mohan et al. (2006) was chosen as the study used comparable substrate and equipment.

Resazurin, an oxidation-reduction indicating dye, was added to each flask for an approximate concentration of 1 mg/L. This indicator changes color depending on the level of oxidation or reduction: from blue when fully oxidized, pink when partially oxidized/reduced, and colorless when fully reduced (see Figure A.8, Appendix A). It allowed for the determination of oxygen contamination in the anaerobic respirometer flasks. Color change was discernable even with dark, opaque seed in the flasks.

Tables 3.1, 3.2, 3.3 and 3.4 outline the reaction flask constituents for Cases A, B-1, B-2 and C respectively. Case A had seven reaction flasks; Cases

B-1, B-2 and C each had eight flasks. In all cases a seed control provided the background biogas produced without substrate.

For Case A (see Table 3.1) two wastewater/seed flasks served as duplicates. Nutrient solution was omitted from these flasks to evince the effect of nutrient amendment. The half-strength dilution flask (½ [wastewater/ seed/ nutrients]) served as both a scale-duplicate and, if it were to produce proportionally more biogas than the full-strength flask, a toxicity indicator. Seed was omitted from the wastewater/nutrients flask to test the microbial activity of the wastewater itself. Seeding a full-scale digester can incur significant cost. A blank flask of de-ionized water served to establish the noise level in gas readings due to pressure changes. During set-up, an eighth flask was broken and so could not be included.

Table 3.1 Case A Respirometer Flask Allocations

Flask ID	Substrate (mL)	Seed (mL)	Nutrient Solution (mL)	De-ionized Water (mL)
Wastewater, Seed, Nutrients	50	120	480	0
Wastewater, Seed (rep A)	50	120	0	480
Wastewater, Seed (rep B)	50	120	0	480
Seed	0	120	0	530
½ (Wastewater, Seed, Nutrients)	25	60	240	325
Wastewater, Nutrients	50	0	480	120
Blank	0	0	0	650

For Case B-1 (Table 3.2) a flask was tested with half the volume of nutrient solution to further investigate the effect and need for nutrient amendment. As in Case A, two wastewater/seed flasks served as duplicates; a half-strength dilution, wastewater/nutrients flask and blank were also included.

Table 3.2 Case B-1 Respirometer Flask Allocations

Flask ID	Substrate (mL)	Seed (mL)	Nutrient Solution (mL)	De-ionized Water (mL)
Wastewater, Seed, Nutrients	50	120	480	0
Wastewater, Seed, 1/2 Nutrients	50	120	240	240
Wastewater, Seed (rep A)	50	120	0	480
Wastewater, Seed (rep B)	50	120	0	480
Seed	0	120	0	530
½ (Wastewater, Seed, Nutrients)	25	60	240	325
Wastewater, Nutrients	50	0	480	120
Blank	0	0	0	650

The seed and substrate samples from Case B-1 were stored at 4°C and used 4 weeks later in Case B-2 (Table 3.3). For Case B-2, two wastewater/ substrate/ nutrients flasks were designated as duplicates to confirm the results from Case B-1. Two seed controls were tested, one with nutrients and one without, to determine if a nutrient solution would affect the background gas production. As in Cases A and B-1, two wastewater/seed flasks served as duplicates; a half-strength dilution, wastewater/nutrients flask and blank were also included.

Table 3.3 Case B-2 Respirometer Flask Allocations

Flask ID	Substrate (mL)	Seed (mL)	Nutrient Solution (mL)	De-ionized Water (mL)
Wastewater, Seed, Nutrients (rep A)	50	120	480	0
Wastewater, Seed, Nutrients (rep B)	50	120	480	0
Wastewater, Seed, 1/2 Nutrients	50	120	240	240
½ (Wastewater, Seed, Nutrients)	25	60	240	325
Seed, Nutrients	0	120	480	50
Wastewater, Seed	50	120	0	480
Seed	0	120	0	530
Blank	0	0	0	650

Case C (Table 3.4) tested a blended wastewater/manure substrate and thus wastewater and manure separately, each with and without nutrients. The seed control included nutrients for comparability with the substrate/nutrient flasks. Because of the multiple scenarios the same controls in Cases A, B-1 and B-2 could not all be utilized in Case C due to the restricted number of flasks in the respirometer.

Substrates were allocated differently with Case C to increase the net biogas, i.e. the biogas differential between the seed controls and substrate flasks. The wastewater and manure were apportioned based on COD rather than volume and blended based on their combined weight-based COD-to-nitrogen ratio (see Appendix C).

Manure is known to have a high microbial activity; a seed source is not traditionally used in such anaerobic digestion applications. For comparability, manure was tested both with the common seed source and as a full volume of manure alone. In this way, manure was tested as a seed source itself.

Table 3.4 Case C Respirometer Flask Allocations

Flask ID	Wastewater (mL)	Manure (mL)	Seed (mL)	Nutrient Solution (mL)	De-ionized Water (mL)
Wastewater, Manure, Seed, Nutrients	170	30	90	360	0
Wastewater, Seed, Nutrients	170	0	90	360	30
Manure, Seed, Nutrients	0	30	90	360	170
Manure, Nutrients	0	120	0	360	170
Seed, Nutrients	0	0	90	360	200
Wastewater, Manure, Seed	170	30	90	0	360
Wastewater, Seed	170	0	90	0	390
Manure, Seed	0	30	90	0	530

Setting up the respirometer was typically a two day process. During the first day, the nutrient solution was blended, the de-ionized water for the flask mixtures and the nutrient solution were autoclaved to drive out dissolved oxygen and the water bath was cleaned. On the second day, the seed sample was collected (with the exception of Case B-2 for which stored seed from B-1 was used), the flask filled with the apportioned constituents, the water bath was filled, the flasks were connected to the gas counting cells and the respirometer software was set up for data collection. See Appendix H for the respirometer set-up protocol used.

Respirometer tests were continued until gas production in all flasks ceased. A flask without nutrient media illustrated to what degree nutrient amendment was required relative to the flask of substrate, seed and nutrients. A flask without seed showed to what degree biodegradation, if any, may occur without seed. The half-strength dilution served as a scale-duplicate and a toxicity indicator if it were to produce proportionally more biogas than the full-strength flask.

3.5 Gas Chromatography

Gas samples of 100 μL were collected from the head space of the reaction flasks and analyzed for methane and carbon dioxide composition by a gas chromatograph (GC-8, Shimadzu Co., Kyoto, Japan) equipped with a thermal conductivity detector (TCD) and 6.1 m nickel columns packed with HayeSep D (100/120 mesh) (Supelco, Bellefonte, Pen.). Two identical columns were installed; the second served as a reference column into which gas was never injected. Helium served as the carrier gas. The column temperature was ramped from 40°C to 110°C at 20°C per minute and the injection port was maintained at 120°C.

Gas tight syringes with push button valves (Series A-2, Fisher Scientific) were used to collect the gas samples. Originally, 1 mL volume syringes were used. These were later changed to 250 µL volume syringes for more precise sample collection. Sampling syringes was purged several times with ambient air before drawing gas samples from the reaction flasks or standard gas cylinders.

Using methane (99.0%) and carbon dioxide (99.8%) gas standards, calibration curves were established for the gas chromatograph column (see Appendix E). Samples of 25, 50, 75 and 100 µL standard gas were analyzed for each calibration curve (methane and carbon dioxide). From this calibration, the composite methane and carbon dioxide fractions, was found. Prior to any sampling event, 50 or 75 µL standard samples of methane and carbon dioxide were analyzed to confirm the calibration. The calibration was considered valid if were acceptable if the gas standard reading's reported percent value (determined from the calibration) was within ten percentage points of the injected value, e.g. a peak area equivalent to 40% for a 50 µL standard methane sample, or a peak area equivalent to 65% for a 75 µL standard carbon dioxide sample.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Substrate Characterization

Table 4.1 outlines the characterization analysis of each substrate (wastewaters A, B and C and manure C). The test parameters and corresponding recommended ranges from the literature serve as guidelines by which to screen a substrate's suitability for anaerobic digestion. This provides a starting point from which to consider financial implications such as the cost of nutrient amendment.

Wastewater A had an ideal pH, adequate COD, and a low sulfate concentration which should produce a clean biogas free of hydrogen sulfide. The decision to measure SCOD was made after testing case A, so this information is not available. Like the others fruit processing wastewaters (B and C) it was low in nitrogen, phosphorus and sulfide. It was also low in alkalinity. These would need to be supplemented in a full-scale operation. Wastewater B had a marginally acceptable pH and a low sulfate concentration, but low COD and alkalinity levels which would not be cost effective for anaerobic digestion. Wastewater C had an adequate COD level, especially considering the high percent SCOD which is a measure of COD readily available to the microbial population. Alkalinity was not tested for wastewater C due to the limited sample volume collected. The low pH may require the addition of substantial alkalinity to a full scale system. Manure C had well proportioned nitrogen (COD:N) and adequate sulfide. The precise phosphorus level was unknown: readings were over the detection limit even at 0.025 dilution factor. This at least indicates that the phosphorus level was greater than 136 mg/L P. The low percent SCOD and VS could make for unstable digestion while the remaining insoluble COD (and solids) are slowly broken down. Marginally high ammonia could cause some inhibition and the higher sulfate levels could produce a biogas with a notable hydrogen sulfide component. Alkalinity could not be tested as the manure sample was too opaque for reliable results.

Table 4.1 Substrate Characteristics

Parameter	Wastewater A	Wastewater B	Wastewater C	Manure C	Recommended Range	Source
pH	7.3	6.3	5.17	n/a	6.5 to 8.2	Speece, 1996
Alkalinity (mg/ L $CaCO_3$)	66	55	n/a	n/a	2000 to 3000 mg/L $CaCO_3$	Speece, 1996
% Total Solids	n/a +	0.10%	0.49%	2.66%	< 10%	
% [VS/TS]	n/a +	80.6%	94.2%	61.7%	As high as possible	
COD (mg/L)	4,624	1,090	4,604	28,818	> 1,000 mg/L	Speece, 1996
Soluble COD (mg/L)	n/a	919	4,248	10,830		
% Soluble COD	n/a	83.5%	92.3%	37.6%		
Ammonia (mg/L N)	< 0.10	< 0.10	2.02	1004*	>50 mg/L, < 1,000 mg/L	Speece, 1996 Calli et al., 2005
TKN (mg/L N)	24	6	22	1673		
Total Nitrogen (mg/L N)	24	6	23	1675		
(mg/L N per 100 mg/L COD)	0.52	0.55	0.49	5.8	3 to 5 mg/L N per 100 mg/L COD	Bouallagui et al., 2004b
Total Phosphorus (mg/L P)	4.22	2.12	3.80	< 136		
(mg/L P per 100 mg/L COD)	0.09	0.19	0.08	< 0.47	0.5 to 1 mg/L P per 100 mg/L COD	Bouallagui et al., 2004b
Sulfide (mg/L)	< 1	< 1	1	3	> 2 mg/L S, <200 mg/L S	Isa et al., 1986
Sulfate (mg/L SO_4)	8	28	11	681	< 5,000 mg/L SO_4 for treatment; < 300 mg/L SO_4 for biogas purity	Isa et al., 1986

+ dish was not fully dry after 6 hours
* reported as mg/kg

4.2 Anaerobic Respirometery

Figures 4.1 through 4.8 illustrate the respirometer results: the gas production rate and cumulative gas production for each of the four different cases, A, B-1, B-2 and C.

4.2.1 Case A

Data points were recorded every 3 hours. Gas production lasted for 34 days. Nearly all biodegradation was completed in 14 days in the wastewater/ seed/nutrients flask, where the nutrient-limited (wastewater/seed) flasks took twice as long. Duplicate flasks exhibited very little relative variation in gas production rate.

The two wastewater/seed flasks, replicates A and B, produced the same amount of gas as the wastewater/seed/nutrients flask but at a slower rate, showing that digestion was nutrient limited A half-strength dilution of the wastewater, seed and nutrients produced nearly half the biogas of the full-strength mixture, evincing no relative toxicity at the full-strength concentration. There was a relative lag in gas production from this half-strength flask and the resazurin dye was pink for the first day following set-up, which both point low seed activity, though maximum gas production rate was as high as the seed and wastewater/seed replicates. The wastewater/nutrients flask had a distinct pink color (see Figure A.8) which indicates some microbial activity, though there was no difference in cumulative gas compared to the de-ionized water. This showed there to be no significant anaerobic activity from the substrate.

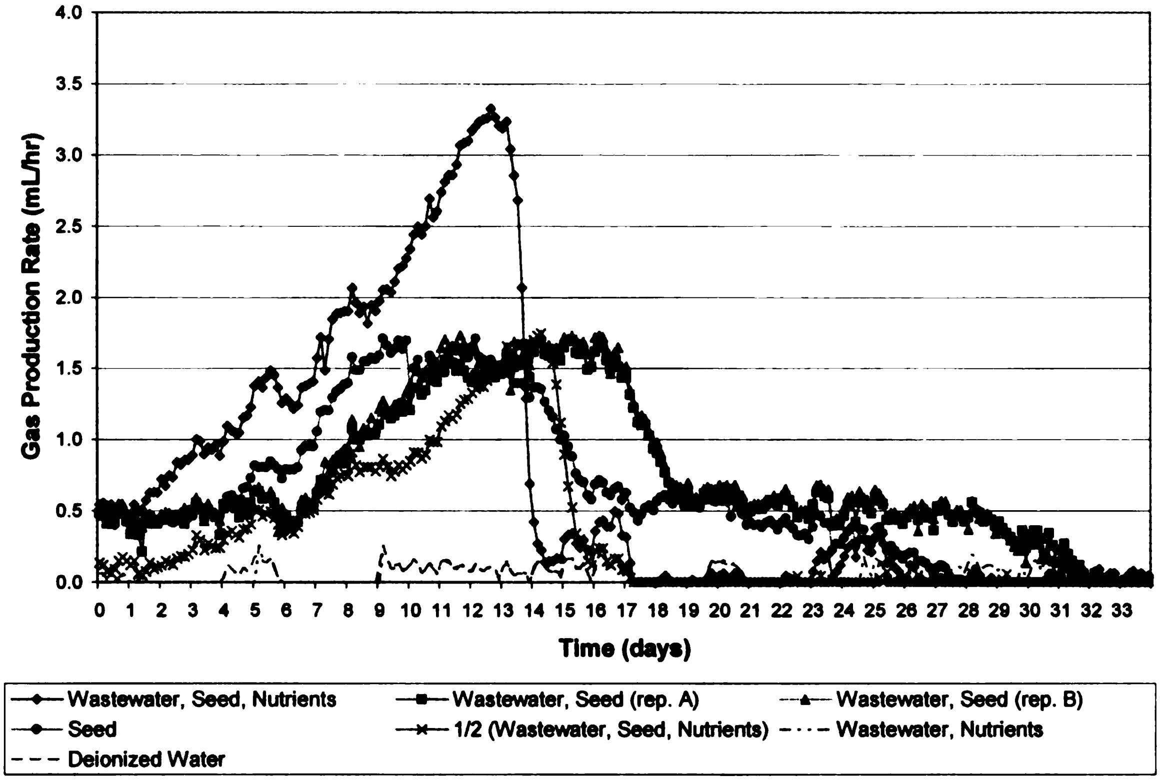

Figure 4.1 Case A Gas Production Rate

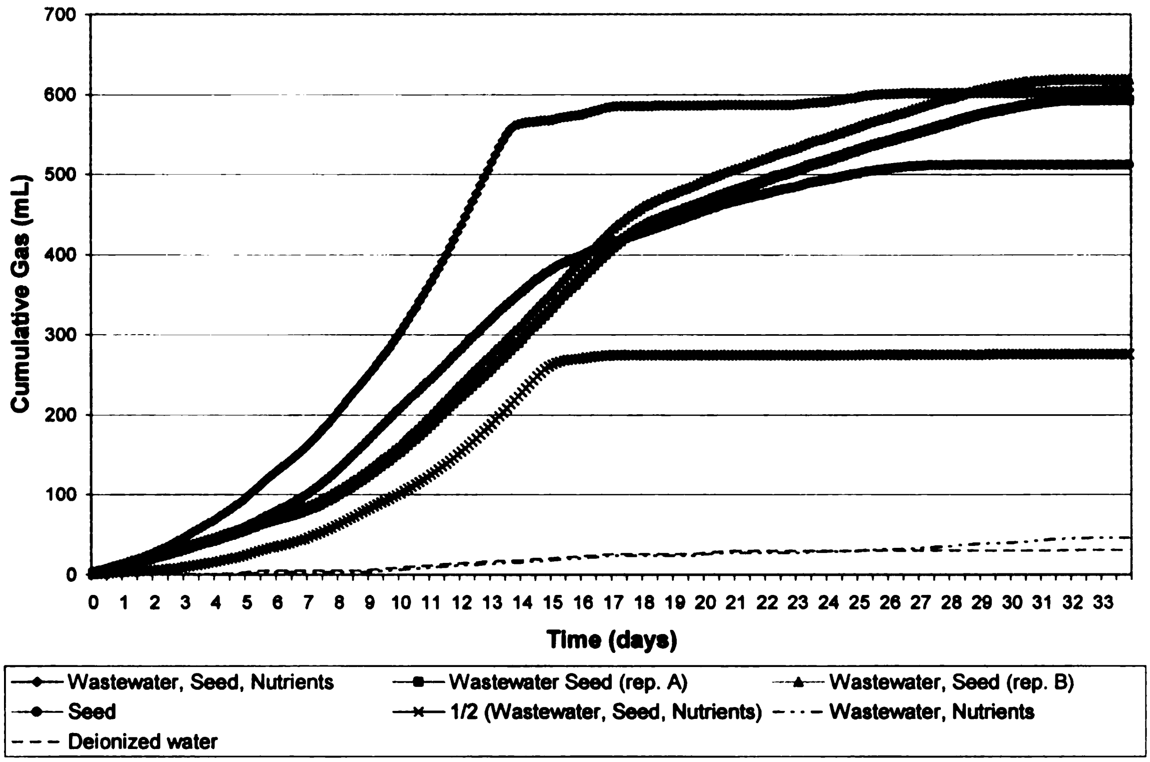

Figure 4.2 Case A Cumulative Gas Production

4.2.2 Case B-1

Data points were recorded every 4 hours. Gas production essentially lasted for 14 days. The wastewater/seed/nutrients flask completed nearly all biodegradation in 11 days. Duplicate flasks exhibited very little relative variation in gas production rate. Both Case B-1 and B-2 (see Figure 4.5 below) exhibited a very low gas production rate at less than 1 mL/hr. This must be attributed to a low activity in the seed sample as the seed controls produced a much lower biogas volume (120 to 130 mL) compared to Case A (over 500 mL).

The two wastewater/seed flasks, A and B, produced the same amount of gas as the wastewater/seed/ ½ nutrients flask though at a slightly slower rate.

From this it appears the reaction was less nutrient limited than in Case A. The waste/seed/nutrients flask produced approximately the same gas volume as the seed, and less than twice as much as the half-strength dilution. This is probably due to oxygen contamination or other situational upset rather than a toxic response to the full-strength nutrient solution concentration, as the same constituents responded favorably in Case B-2 (section 4.2.3). The wastewater/nutrients flask produced less gas than the de-ionized water, again evincing no active anaerobe population in the substrate.

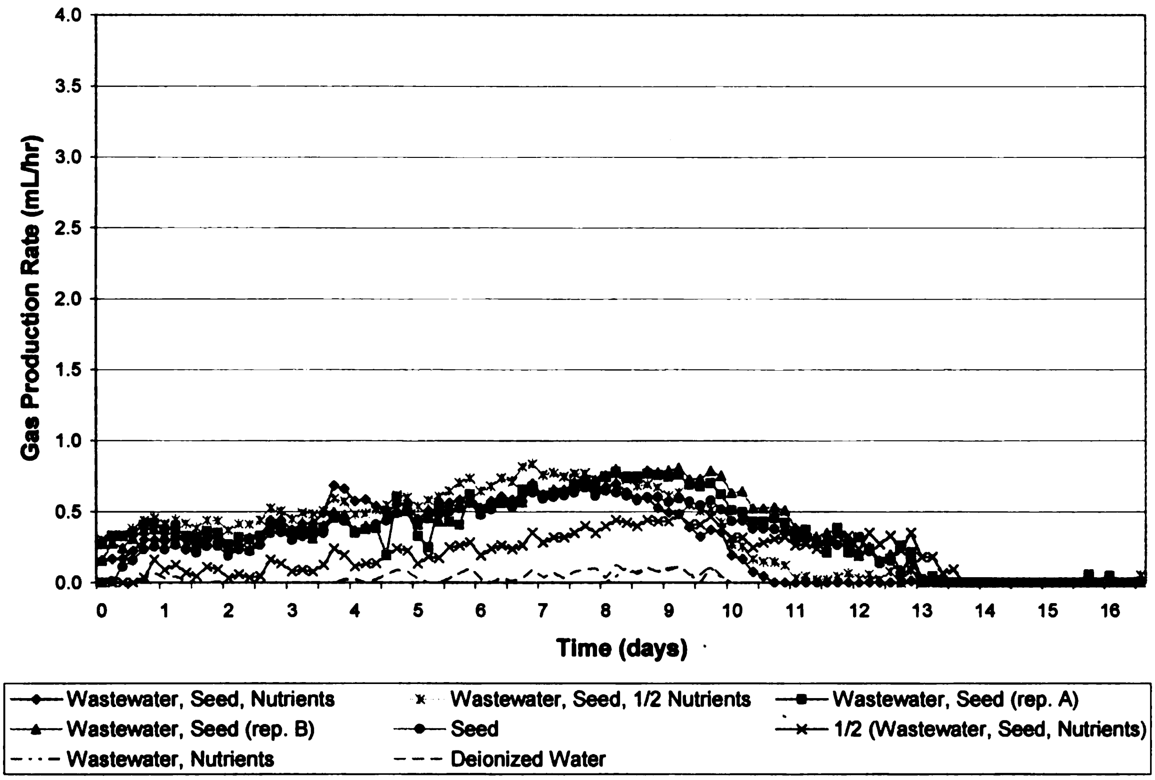

Figure 4.3 Case B-1 Gas Production Rate

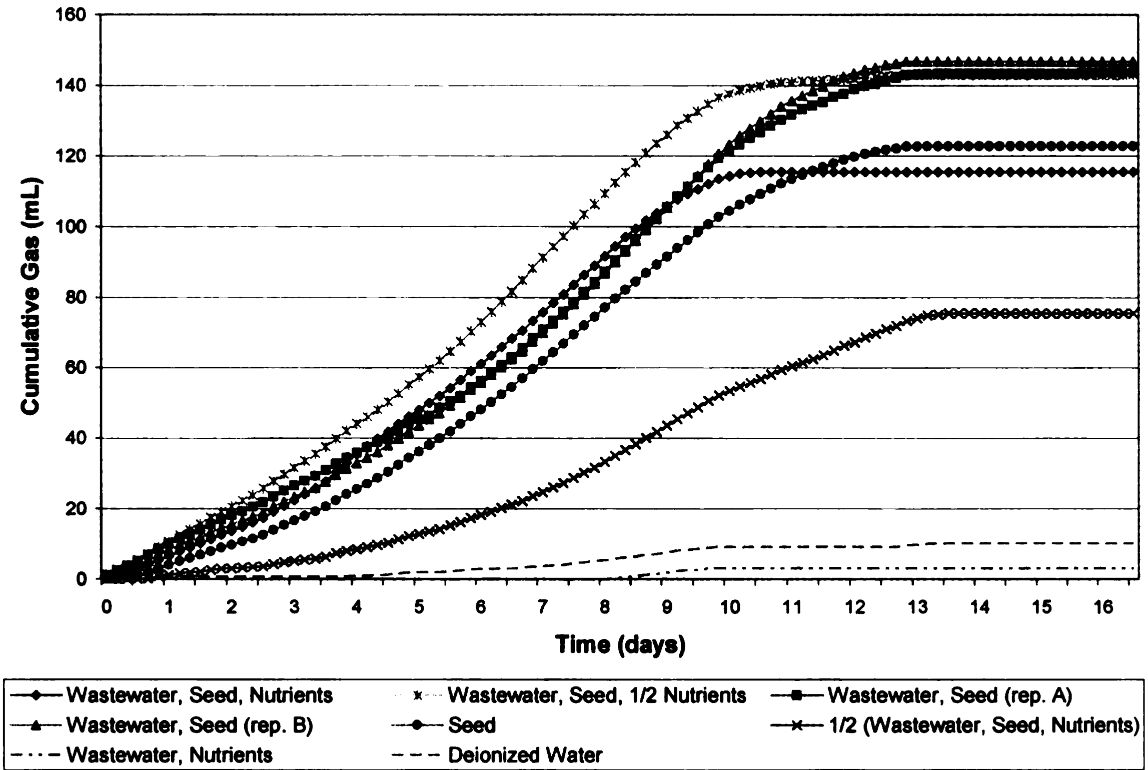

Figure 4.4 Case B-1 Cumulative Gas Production

4.2.3 Case B-2

Data points were recorded every 4 hours. Gas production lasted for 27 days. The two wastewater/seed/nutrients flasks, replicates A and B, completed biodegradation in 20 days. These duplicate flasks exhibited very little relative variation in gas production rate. The nutrient solution corresponded with a higher gas production rate: the wastewater/seed/nutrients flasks had a peak rate of 0.9 mL/hr, where the wastewater/seed flask had a lower rate at 0.6 mL/hr but more sustained for 4 days longer. There was no significant gas production from the wastewater/ seed/ ½ nutrients flask, which was attributed to a loose cap.

Overall, gas production rates for Case B-2 were comparable to Case B-1. Gas production was limited during the first week. This lag was attributed to seed inactivity due to storage: the same seed sample was used in both B-1 and B-2 but was stored at 4°C for 30 days prior to Case B-2. These results are consistent with previous observations which corresponded length of storage to lag time (Shelton and Tiedje, 1984)

There was similar cumulative gas production from the wastewater/seed flask and the two wastewater/seed/nutrients flasks, replicates A and B. Flasks without nutrients had a shorter lag time, suggesting that digestion was less nutrient-limited than Case A.

The marginal net biogas from Cases B-1 and B-2 illustrated the importance of testing substrates based on COD per flask rather than by volume, and perhaps allocating less seed, in order to ensure significant differentials in gas production between the substrate and seed control flasks. As discussed in section 3.3, Case C was set up differently based on this observation.

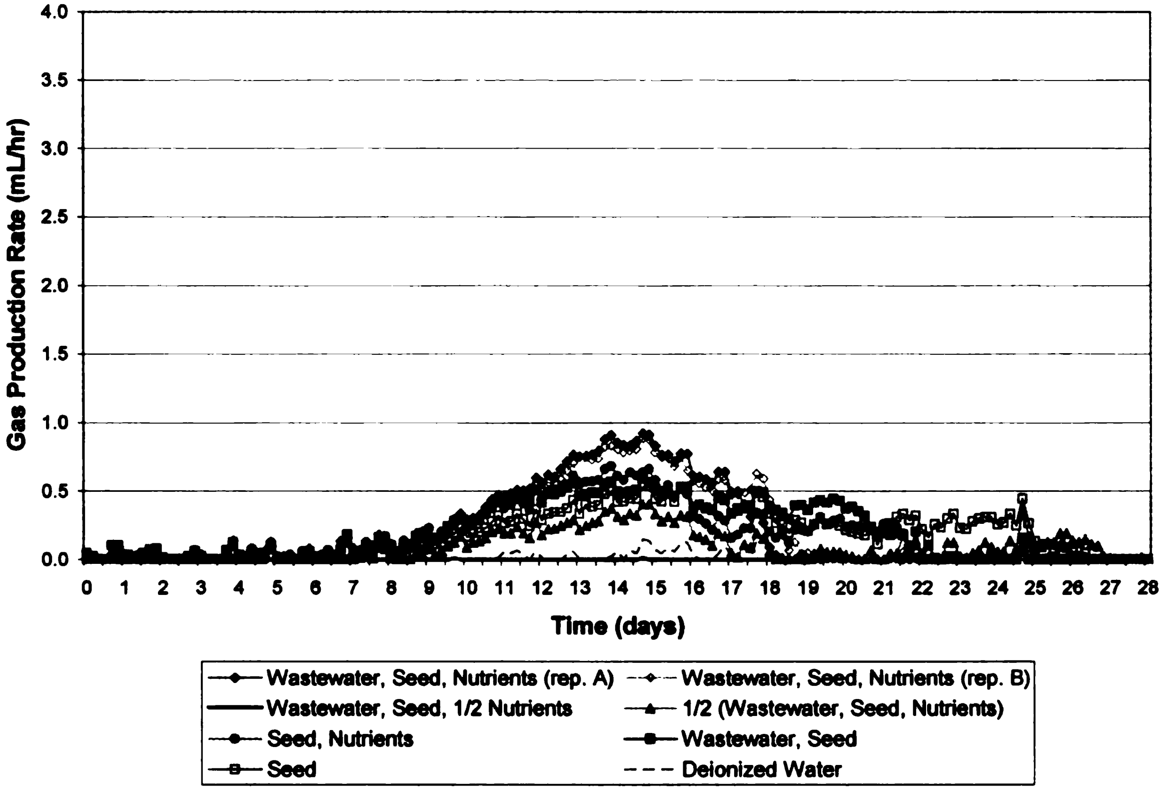

Figure 4.5 Case B-2 Gas Production Rate

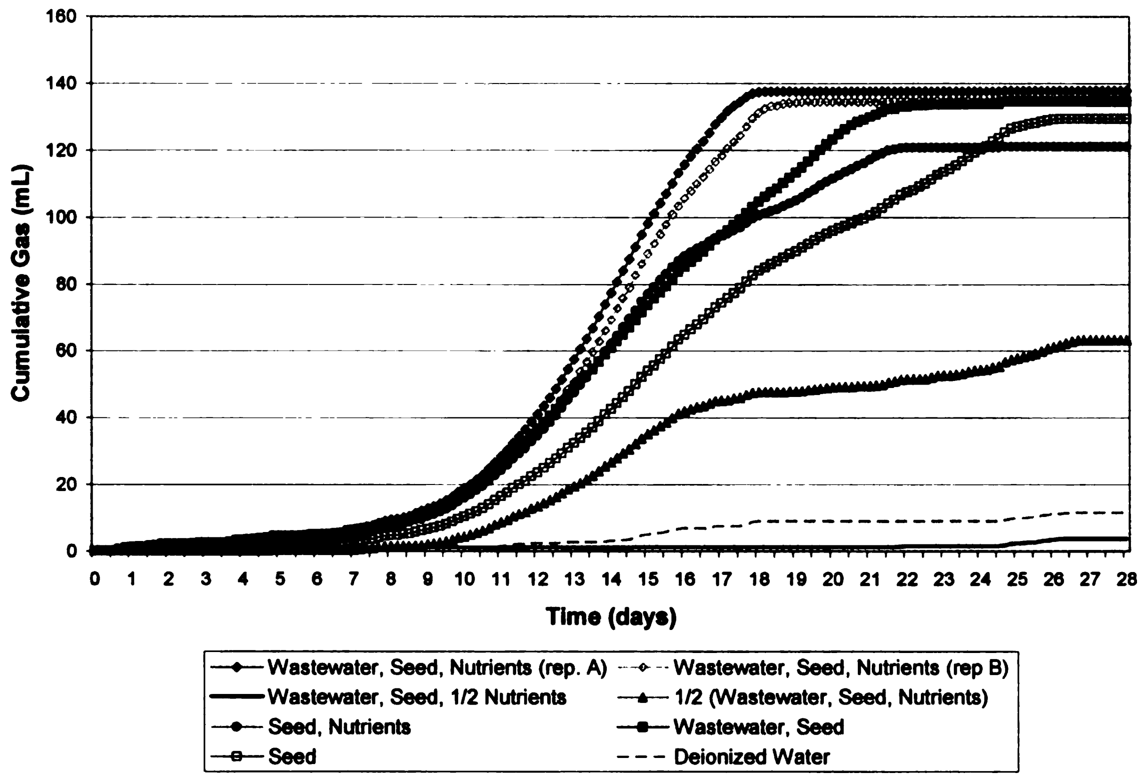

Figure 4.6 Case B-2 Cumulative Gas Production

4.2.4 Case C

Data points were recorded every 4 hours. A larger quantity of substrate, both in terms of volume and COD, and a smaller quantity of seed were allocated to each flask. This was done to increase the relative net biogas production, but also inherently resulted in a longer digestion time. Gas production lasted for 54 days.

Gas production was considerably unstable for Case C compared to the previous cases, with multiple peaks in the gas production rate for each active flask. This may be attributed to several factors. The seed sample may have been of poor quality, as the seed control was itself unstable, as seen by the fluctuations in the gas production rate. To compound the effect of the unstable seed, the manure/nutrients flask also went through fluctuations in productivity with multiple gas production rate peaks. This suggests that the manure presented a more complex substrate, which is supported by its low percent SCOD. Another factor is the low pH of the cherry wastewater. The wastewater/seed flask had no significant gas production, a fact which could not be attributed to oxygen contamination in this case as evinced by the consistent colorless resazurin dye throughout the trial. The poor results must be due to inhibition or a lack of essential nutrients or alkalinity to offset the low pH. Cherries do contain polyphenols which are known to inhibit microbial activity. However, the cherry wastewater/seed/nutrients flask was not notably inhibited, which suggests polyphenol inhibition was not the main factor.

The blended substrate (wastewater and manure) performed better than either substrate individually. Each substrate reached equilibrium faster when mixed with the nutrient solution, though the nutrient solution did not correlate to a higher total gas volume. A given 30 mL of manure produced more gas when combined with 90 mL of seed than with another 90 mL of manure.

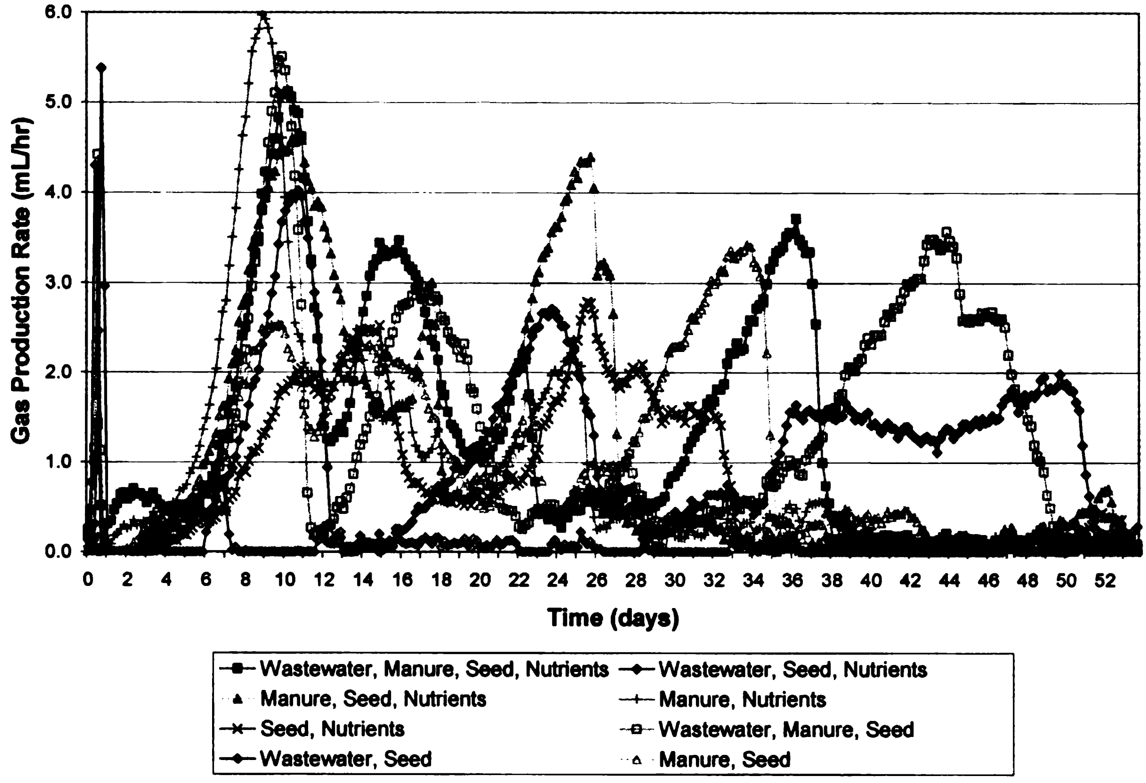

Figure 4.7 Case C Gas Production Rate

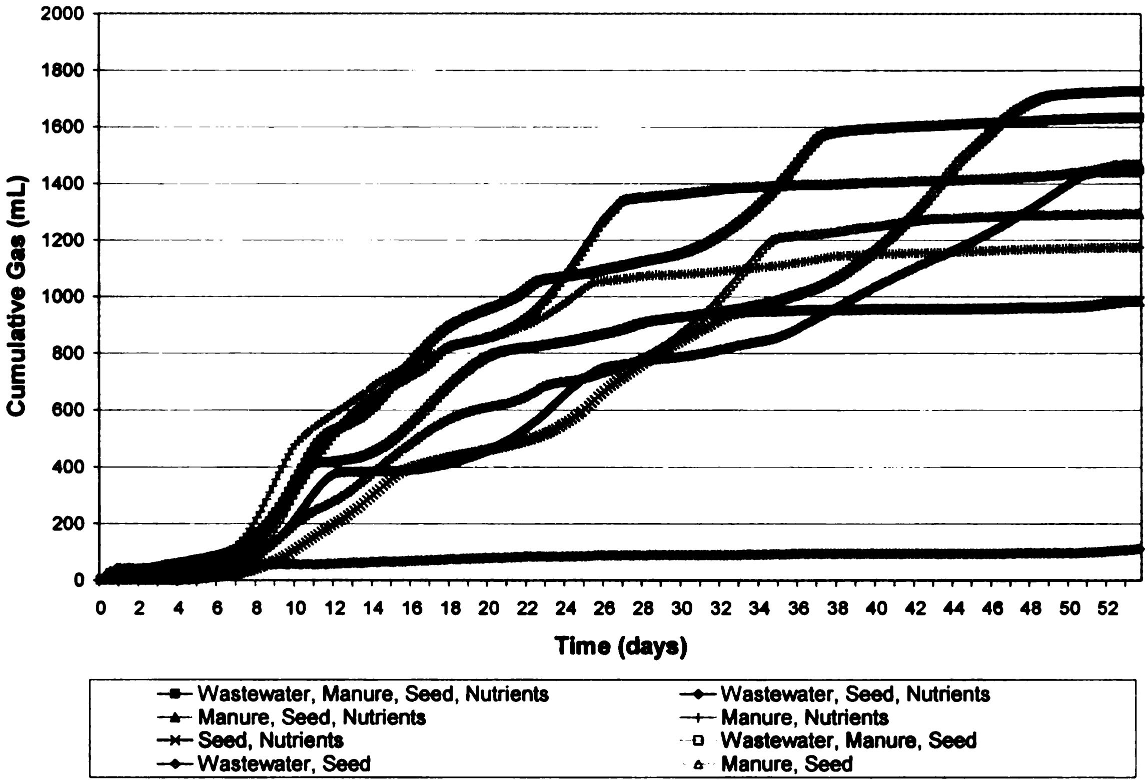

Figure 4.8 Case C Cumulative Gas Production
Note: Data were recorded every four hours. For clarity, points are only shown for every eight hours.

4.3 Biogas Analysis

Tables 4.2, 4.3, 4.4 and 4.5 present the biogas analyses for Case A, B-1, B-2 and C, respectively. "COD from Substrate" is the amount of COD available from the substrate in each given flask, based on the volume of substrate added and its measured COD. The theoretical methane potential (TMP) is determined by the following stoichiometric conversion (Speece, 1996):

$$1 \text{ g COD} = 395 \text{ mL } CH_4 \text{ at } 35°C \quad [4.1]$$

TMP is calculated at 35°C so as to be comparable to the measured data. From this, the theoretical biogas potential (TBP) was calculated by assuming 70%

methane composition. The total biogas reported is the cumulative volume measured by the respirometer. Net biogas was calculated as the difference between the substrate flask and its respective seed control.

An effort was made to analyze gas samples at a period in the trial when the gas production rate was maximized for a majority of the flasks, barring any equipment malfunctions. It was assumed this point in the trial best represented the ideal operating conditions of a full scale reactor when methane production should also be maximized.

Gas sampling for Case A (Table 4.2) was conducted just as the gas chromatograph was being set up and the respirometer trial was ending (day 33 and 34). Due to equipment malfunctions and time constraints there was not an opportunity to analyze a sample from the wastewater/seed/nutrients flask. A significant background level of methane appeared in sample from the de-ionized water flask. The syringe-flushing method was revised due to this cross-contamination.

Table 4.2 Case A Biogas Analysis

Flask ID	COD from Substrate (mg)	TBP (mL at 35°C)	Total Biogas (mL)	Net Biogas (mL)	%TBP achieved	% CH_4
Seed	-	-	512.01	-	-	64.5
Wastewater, Seed, Nutrients	54.5	130.46	605.7	93.69	71.8%	n/a
Wastewater, Seed (rep. A)	231.2	130.46	592.3	80.29	61.5%	65.6
Wastewater, Seed (rep. B)	231.2	130.46	618.85	106.84	81.9%	73.0
½ (Wastewater, Seed, Nutrients)	115.6	65.23	275.75	19.75	30.3%	47.0
Wastewater, Nutrients	231.2	130.46	45.82	45.82	35.1%	37.6
De-ionized water	-	-	31.21	31.21	-	25.8

For Case B-1 (Table 4.3) gas samples were collected and analyzed on day 6 from wastewater/seed/nutrients, wastewater/seed (rep. B) and wastewater/nutrients) and day 12 from all flasks. Wastewater/seed (rep. A) was left un-sampled as a control to ensure that the act of gas sampling did not impose any negative affect on the gas flow measurements. Active flasks with full-strength wastewater all exhibited methane fractions over 60%. The half-strength flask (½(wastewater/seed nutrients)) achieved over 90% of its TBP, though with an average methane fraction of 32%, the %TBP may be skewed by background noise considering the de-ionized water had a reported 10 mL biogas. Unseeded wastewater produced negligible biogas and methane.

Table 4.3 Case B-1 Biogas Analysis

Flask ID	COD from Substrate (mg)	TBP (mL at 35°C)	Total Biogas (mL)	Net Biogas (mL)	%TBP achieved	% CH_4
Seed	-	-	122.74	-	-	68.5
Wastewater, Seed, Nutrients	54.5	30.75	115.44	0	0.0%	54.2, 65.2
Wastewater, Seed, 1/2 Nutrients	54.5	30.75	143.08	20.34	66.1%	70.9
Wastewater, Seed (rep. A)	54.5	30.75	143.65	20.91	68.0%	n/a
Wastewater, Seed (rep. B)	54.5	30.75	146.79	24.05	78.2%	47.8, 68.1
½ (Wastewater, Seed, Nutrients)	27.3	15.38	75.40	14.03	91.2%	19.6, 44.6
Wastewater, Nutrients	54.5	30.75	3.14	0	0%	4.8
De-ionized water	-	-	10.19	10.19	-	5.7

For Case B-2 (Table 4.4) gas samples were collected and analyzed on day 20. The wastewater/seed/½ nutrients flask was not sampled, as the gas production was negligible. Though Including nutrients with the seed control had no affect on total gas production, net biogas was calculated from each flask's corresponding seed control (i.e. with or without nutrients). The half-strength flask (½(wastewater/seed nutrients)) had low biogas production and correspondingly low methane of 39%, comparable to its B-1 counterpart at an average 32%

Table 4.4 Case B-2 Biogas Analysis

Flask ID	COD from Substrate (mg)	TBP (mL at 35°C)	Total Biogas (mL)	Net Biogas (mL)	%TBP achieved	% CH_4
Seed, Nutrients	-	-	121.12	-	-	68.5
Wastewater, Seed, Nutrients (rep. A)	54.5	30.75	137.71	16.59	53.9%	59.3
Wastewater, Seed, Nutrients (rep. B)	54.5	30.75	135.44	14.32	46.6%	74.8
Wastewater, Seed, 1/2 Nutrients	54.5	30.75	3.88	0	0.0%	n/a
½ (Wastewater, Seed, Nutrients)	27.3	15.38	63.31	2.75	17.9%	38.7
Seed	-	-	129.51	-	-	56.7
Wastewater, Seed	54.5	30.75	134.49	4.98	16.2%	28.2
De-ionized water	-		11.60	11.6	-	5.6

For Case C (Table 4.5) gas samples were collected and analyzed on days 11 and 14. The methane fraction varied significantly for some of the flasks. A manure/seed lab duplicate had a difference of 12% methane and average value of 71.8%. This suggests that the variance between sampling days may reflect this same resolution.

The blended substrate (wastewater and manure) produced significantly more gas than either individually, though gas production from the blended substrate was less than the sum of that from wastewater plus that from the manure. Interestingly, the individual substrates (wastewater or manure) achieved a higher %TBP with nutrient amendment at approximately 100% for each, where the blended substrate reached a higher %TBP without nutrient addition.

Table 4.5 Case C Biogas Analysis

Flask ID	COD from Substrate (mg)	TBP (mL at 35°C)	Total Biogas (mL)	Net Biogas (mL)	%TBP achieved	% CH_4
Seed, Nutrients	-	-	983.6	-	-	61.0, 81.7
Wastewater, Manure, Seed, Nutrients	1647	929.5	1632.4	648.8	69.8%	40.0, 57.9
Wastewater, Seed, Nutrients	783	441.7	1440.1	456.5	103.4%	27.3, 62.8
Manure, Seed, Nutrients	865	487.8	1467.0	483.4	99.1%	63.3, 77.3
Manure, Nutrients	3458	1951.4	1173.1	1173.1	60.1%	63.7, 70.5
Wastewater, Manure, Seed	1647	929.5	1725.7	742.1	79.8%	58.8, 62.2
Wastewater, Seed	783	441.7	110.0	0	0.0%	5.2, 17.5
Manure, Seed	865	487.8	1292.5	308.9	63.3%	70.9, 71.8*

*averaged value from lab duplicates

4.4 Summary

All three case studies had respective correlating substrate characterizations and respirometer gas analyses. Substrate analyses for the Case A wastewater sample suggested a decent candidate for anaerobic treatment, with a neutral pH and a mid-range COD level with a high SCOD, though it would require nutrient amendment including nitrogen, phosphorus and alkalinity. This was confirmed by the respirometer results, achieving roughly 72% theoretical biogas potential (assuming 70% methane) and an average methane fraction of 69% from the wastewater/seed replicates. The difference in gas production rates between the wastewater/seed flasks and that with nutrients confirmed the benefit of nutrient amendment.

Substrate characterizations for Case B suggested a poor candidate for anaerobic treatment, mainly due to the dilute COD level in addition to low alkalinity and nutrient levels. Respirometer results were poor for both Case B-1 and B-2. Percent TBP recovered was higher for B-1 than B-2, though these values may not be significant considering the background level from the de-ionized water were in the same range as the net biogas from wastewater. Though biogas production was limited, the average methane fraction (for the seeded wastewater flasks with and without nutrients) was 63% for B-1 and 67% for B-2.

Wastewater and manure substrates were blended in Case C to optimize anaerobic treatment potential. The blended substrate had a near optimal COD/N ratio, compared with the nitrogen deficient wastewater and the nitrogen rich manure. Respirometer and gas chromatography test results were complex and inconsistent in this case. Based on the net biogas, biodegradation was improved by blending. While the manure/nutrients flask produced the highest net biogas, it had a lower volume than the manure/seed/nutrients per 30 mg COD of manure added. The percent TBP recovery suggests that manure was the better candidate, followed by the blended substrate and then the wastewater. Manure alone also had the highest methane fraction with an average of 70%, where the blended substrate had an average of 55% methane and the wastewater an average of 28% methane. Considering just the fruit processing wastewater C, anaerobic biodegradability was significantly improved by blending with liquid dairy manure.

4.5 Discussion

Screening wastewater for anaerobic biogas potential is important because substrate characterization alone may not identify sources of inhibition. This was illustrated in Case C where manure exhibited an unstable gas production rate and cherry wastewater completely inhibited biogas production in the respirometer, for which there were no definitive indication from the substrate characterizations. This is especially true for the blended substrates which did not exhibit the explicit improvement in gas production as anticipated by the characterization results.

Case C does not represent conditions as they would likely occur in the case of proposed blending circumstances. All processors (A, B and C), from whom samples were collected for testing, added their storm water to their plant wastewater and land applied this mixture. This may be acceptable practice for land application, but in pursuing anaerobic digestion storm water would be kept separated and other water minimization practices would likely be implemented to further concentrate the COD loading. Blending manure with a highly soluble COD waste stream could then potentially stabilize gas production. Wasted food product that does not meet specifications would also be much more concentrated and appropriate for supplemental blending perhaps.

The experiments conducted to support this protocol development yielded interesting findings regarding the characteristics of fruit processing wastewater. For Cases A, B-1 and B-2, the cumulative gas curves from the optimized flasks (wastewater/seed/nutrients) exhibited a classic batch-system growth curve, i.e.

an initial lag period followed by a log inverse increase. Without nutrient amendment (wastewater/seed), the lag was increased in the slope of the growth curve was decreased.

From the varied seed gas production rates among the respriometer trials, it is clear that anaerobic digestate activity can vary greatly (even from the same digester processing the same substrate over time). Therefore, it is important to note the relative seed activity so that inaccurate conclusions are not drawn regarding the substrate's biodegradability.

In developing the protocol, several procedural techniques were found that can impact results. This includes the ratio of substrate to seed in the respirometer flasks. There is little precedent set by previous literature as the majority of studies concern the treatment of municipal sludge or manure in which case the substrate being treated provides its own seed source. Cases A, B-1 and B-2 illustrate one option in which a set volume of substrate is added in proportion to a set volume of seed. The specific ratio may be adjusted to model a plug-flow anaerobic digester. Case C offers an alternative in which a substrate volume is selected to provide a specific amount of COD to each flask. This option allows more control in insuring an ample net biogas potential and the respirometer trial length. A subsequent question is whether to ration the nutrient solution in relation to the seed volume, the substrate volume or both.

CHAPTER 5: ANAEROBIC DIGESTION FEASIBILITY PROTOCOL

5.1 Protocol Overview

Based on the lab results (Chapter 4) and several processing plant tours and interviews this protocol was revised to its current edition. Step-by-step instructions for the protocol are provided in Appendix H with supporting material in Appendices I and J.

This protocol is intended to serve fruit and vegetable processors by analyzing a waste stream (substrate) to determine the applicability of anaerobic digestion as a treatment method and/or energy source. Food processors and area farmers pursuing a regional digester may also test wastewater-manure blends. An individual processor may be interested in installing a digester for the plant's wastewater treatment or a group of processors and/or farmers may be organizing a regional digester. The protocol includes methods to assess a waste stream's pretreatment and operating requirements, estimate biogas production using an anaerobic respirometer and analyze the subsequent methane fraction with gas chromatography. It provides recommendations for suitable methane applications. Processor objectives, wastewater parameters and respirometer results are considered to determine if further investigation such as a pilot-scale digester is appropriate. To facilitate the collection of pertinent information from the processor, assessment worksheets were developed based on literature and site-specific experience (see Appendix J). Conclusions for an individual processor may include a recommendation to consider a regional digester.

5.2 Plant Profile

Several fruit and vegetable processors were interviewed to gain insight to important considerations for this screening procedure. Due to the seasonality of fruit and vegetables, processors commonly handle a variety of commodities throughout the year. Wastewater may widely fluctuate in flow, pH, COD strength and nutrient concentration, all of which can impact the stability of anaerobic digestion. Therefore, a critical step is to profile these changes throughout the year as accurately as possible. For the purpose of regulatory compliance, many processors keep record of monthly wastewater flows and its characteristics such as pH, BOD, macronutrients and some minerals. Wastewater regulations often require processors to monitor BOD, which reflects aerobic biodegradability; however, COD is easier to analyze and more appropriate for anaerobic applications and thus the reference test for this protocol as with most anaerobic literature.

Once the wastewater profile is established, multiple samplings may be needed for testing to represent high, low and average wastewater conditions. To maintain representative results, waste stream samples should be analyzed and set up in the respirometer as soon as possible.

5.3 Energy Potential

Other important considerations for anaerobic treatment often include energy potential. Rough estimates of methane production and heating potential can be calculated based on the wastewater COD content. The theoretical methane equivalence of 1 g COD is 395 mL CH_4 at 35°C (or 350 mL CH_4 at STP) (Speece, 1996). This converts to 12.66 GJ (12 MM Btu) per 1000 kg COD destroyed. Actual methane production will vary with reactor efficiency. Given a processor's current cost for natural gas, and assumed reactor and boiler efficiencies, rough cost offsets from potential methane production can be calculated. This represents the maximum energy potential. If energy recovery is important to the processor and this value is too low, the opportunity for anaerobic digestion will be limited.

5.4 Substrate Characterization

The COD to energy conversions described above do not account for variability in substrate biodegradability. To properly assess the potential for anaerobic treatment of a specific waste stream, several other parameters must be analyzed.

In considering anaerobic treatment for a nutrient-deficient waste stream, the cost for nutrient amendment in full-scale operation should be weighed against potential cost offset by biogas production. Most food processing wastes may be lacking in trace metals such as iron, nickel, zinc and cobalt, which are known to be highly limiting of methanogenesis. If nutrient amendment is too costly, the opportunity to blend the waste stream in a regional digester should be considered and tested using this protocol.

5.5 Anaerobic Respirometer

The ultimate step in the protocol is respirometer testing to analyze biogas potential and methane production. Testing different combinations of wastewater or blended substrate with seed and/or nutrient solution can provide information about the biodegradability of the wastewater. Comparison of the cumulative gas and gas production rate curves can show signs of inhibition, nutrient limitation and seeding requirements. Gas chromatography analysis of headspace samples can confirm the degree of biodegradation and methane production. From these considerations an educated assessment to pursue anaerobic treatment can be garnered.

CHAPTER 6: CONCLUSIONS

6.1 Conclusions

The objectives of the project were successfully met. A general protocol was developed to pre-screen fruit and vegetable processing waste streams for anaerobic treatment using anaerobic respirometry. This protocol was tested under three conditions with distinguishing results indicating appropriate or inappropriate substrates for anaerobic treatment.

6.2 Future Applications

There are several opportunities to improve and streamline the screening protocol for future applications. Characterizing the seed sample prior to respirometer testing including COD and volatile suspended solids would provide better insight to the seed biogas potential, as the experiments in this study showed great variability in the seed activity over time even from the same digester. A standard seed source maintained in the lab may provide the most benefit. A validation study of the protocol with a full-scale system is imperative and may incite further improvements in the protocol. It may be of interest to compare the respirometer method to the conventional serum bottle method.

If an expanded respirometer of 16 or more reaction flasks were available, then it should be possible to run flask duplicates in which CO_2 is scrubbed out from one of each pair. This could allow for the gas counter to directly measure methane production. Gas chromatography analyses would still be advisable to ensure carbon dioxide was fully removed and to confirm methane concentrations.

APPENDICES

APPENDIX A

ANAEROBIC RESPIROMETER COMPONENTS

Figures A-1 through A-8 show the various components of the respirometer equipment. In Figure A-1 the stir plate is shown, upon which the water bath is placed in Figure A-2. The gap in the water bath lid provides space for the gas transport lines which connect the reaction flasks to the flow measuring cells. The heating/cooling unit is not yet connected to the water bath in this view.

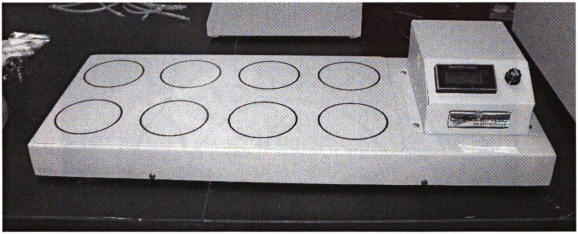

Figure A.1 Stir Plate

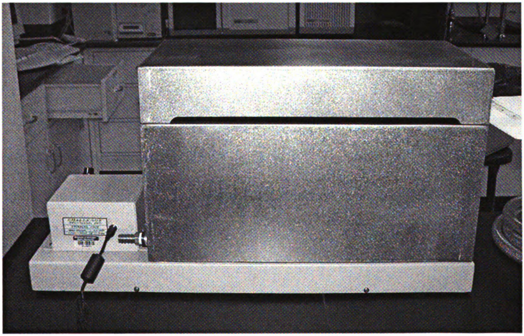

Figure A.2 Rear View of Water Bath on Stir Plate

Hose connections at the water bath are shown in Figure A-3. The left hose is the inlet line to the water bath; the right hose is the gravity return line to the heating/cooling unit.

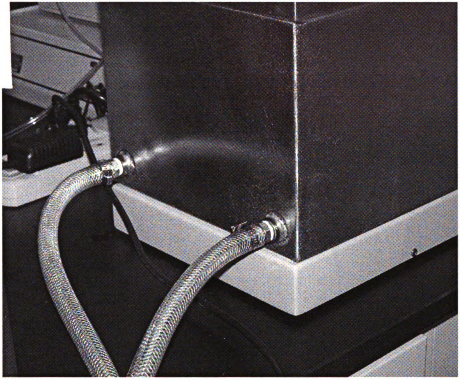

Figure A.3 Water Bath Hose Connections to Heating/Cooling Unit

Flow rate through the water bath was adjusted by the blue handle seen on the heating/cooling unit's left side (Figure A-4). The valve on top allows for the unit to be filled or drained. The water bath must be elevated above the unit to accommodate the gravity return line.

Figure A.4 Heating/Cooling Unit Set at 35°C

Figures A-5 through A-7 illustrate the gas collection components. Arrows indicate the direction of gas flow. In Figure A-5, a syringe connected to the gas collection line is shown inserted into an empty reaction flask septum cap. The syringe is inserted into the septum cap at the thicker edge and at an angle to prevent strain, as per the manufacturer's instructions.

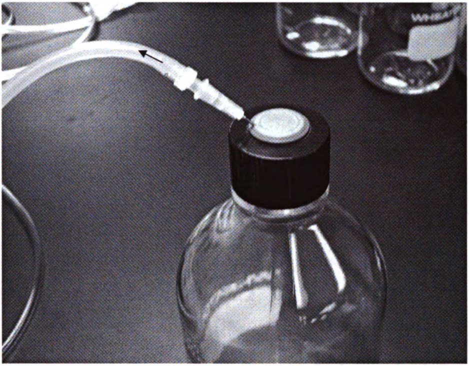

Figure A.5 Empty Reaction Flask with Syringe and Gas Collection Line

From the reaction flasks, gas flowed through the syringe and gas collection line to flow measuring cells. An individual flow measuring cell is shown removed from the base in Figure A-6. Gas flows from the reaction flask up the left tube, then through the cell oil in discrete bubbles of calibrated volume where they interrupt a laser counter (labeled in Figure A-6). The bubbles then flow out of the cell through the right tube to a common manifold and out the exhaust port. Figure A-7 shows all eight flow measuring cells connected to the center manifold. Tubing can be seen (as labeled in Figure A-7) connected to the exhaust port which led to a gas collection bag (not pictured) for safety.

In Figure A-8, the reactions flasks are shown being stirred while in the water bath and connected to the flow measuring cells. An oxidation-reduction

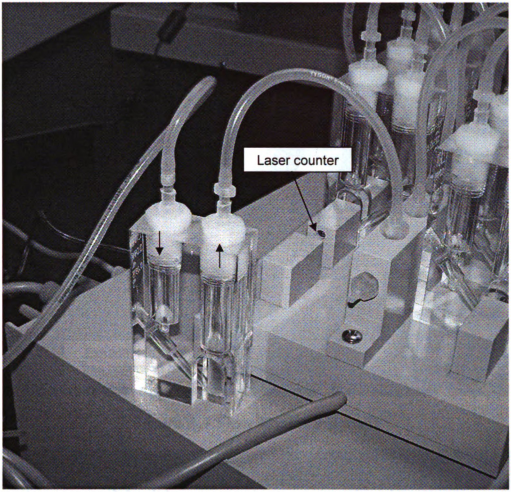

Figure A.6 Individual Flow Measuring Cell

indicator, resazurin, was added to each flask to indicate aerobic conditions. With no microbial activity in the de-ionized water, the resazurin is fully oxidized and a dark indigo color. Resazurin transitions to bright pink when minimal reduction occurs. This can be seen in flask 6 (top right corner, Figure A-8) containing wastewater and nutrients, which shows there is limited microbial activity though not fully anaerobic conditions. When fully reduced, the indicator is colorless as seen in the seeded flasks (1 through 5, the five flasks to the left in Figure A-8). If oxygen were present in the seeded flasks, the indicator would be oxidized and turn the solution a dark maroon color.

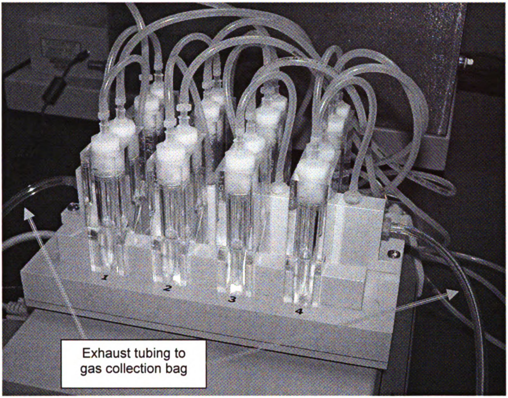

Figure A.7 Flow Measuring Cells

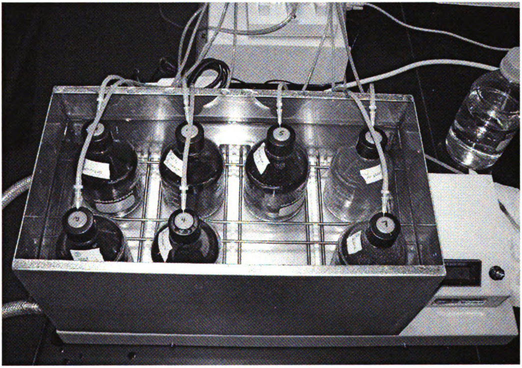

Figure A.8 Case A Flasks in Water Bath

APPENDIX B

SUBSTRATE CHARACTERIZATION ANALYSES – RAW DATA

Table B.1 Case A Substrate Characterization Raw Data

Parameter	Sample No.	Dilution Factor	Original Reading	Reported Value	Reporting Limit
pH	1		7.41		
	LD 1		7.20		
Alkalinity (mg/L $CaCO_3$)	1	1	66	66	
Total Solids (g/L)	Blank	0.025 L	0.000 g	0	
	1	0.025 L	2.341‡	93.64	
	LD 1	0.025 L	1.888‡	75.52	
COD (mg/L)	Standard (1000 mg/L)	1.00	1050	1050	
	2	0.25	1156	4624	
Total Phosphorus (mg/L P)	Standard (3.92 mg/L P)	0.20	0.85	4.25	
	1	0.25	OR	OR	1.10⁺
	2	0.25	1.11	4.44	
	LD 2	0.25	1.00	4.00	
Ammonia (mg/L NH_4-N)	A&L			BDL	0.10*
Nitrate + Nitrite (mg/L N)	A&L			0.40	
TKN (mg/L N)	A&L			24	
Sulfide (mg/L)	A&L			BDL	1*
Sulfate (mg/L SO_4)	A&L			8	

LD = Lab Duplicate
‡ Liquid left in dish after 6 hours
OL = Over Limit
⁺ Upper limit
BDL = Below Detection Limit
* Lower limit

Table B.2 Case B Substrate Characterization Raw Data

Parameter	Sample No.	Dilution Factor	Original Reading	Reported Value	Reporting Limit
pH	1		6.42		
	2		6.52		
	3		6.62		
Alkalinity (mg/L $CaCO_3$)	4	0.20	11	55	
Total Solids (g/L)	Blank	0.025 L	0.0000 g	0.00	
	1	0.025 L	0.0251 g	1.00	
	2	0.025 L	0.0255 g	1.02	
	LD 2	0.025 L	0.0269 g	1.08	
	3	0.025 L	0.0261 g	1.04	
Volatile Solids (g/L)	Blank	0.025 L	0.0014 g	0.06	
	1	0.025 L	0.0198 g	0.79	
	2	0.025 L	0.0205 g	0.82	
	LD 2	0.025 L	0.0217 g	0.87	
	3	0.025 L	0.0215 g	0.86	
COD (mg/L)	Standard (1000 mg/L)	1.00	1044	1044	
	1	0.25	265	1060	
	2	0.25	280	1120	
SCOD (mg/L)	1	0.25	224	896	
	2	0.25	239	956	
	LD 2	0.25	226	904	
Total Phosphorus (mg/L P)	Standard (3.92 mg/L P)	0.20	0.73	3.65	
	1	0.25	0.52	2.08	
	LD 1	0.25	0.57	2.28	
	2	0.25	0.51	2.04	
	3	0.25	0.52	2.08	
Ammonia (mg/L NH_4-N)	A&L			BDL	0.10*
Nitrate + Nitrite (mg/L N)	A&L			BDL	0.05*
TKN (mg/L N)	A&L			6	
Sulfide (mg/L)	A&L			BDL	1*
Sulfate (mg/L SO_4)	A&L			28	

LD = Lab Duplicate

OL = Over Limit
$^+$ Upper limit

BDL = Below Detection Limit
* Lower limit

Table B.3 Case C Wastewater Characterization Raw Data

Parameter	Sample No.	Dilution Factor	Original Reading	Reported Value
pH	1		5.17	
Total Solids (g/L)	Blank	0.025 L	-0.0006 g	-0.02
	1	0.025 L	0.1223 g	4.89
	LD 1	0.025 L	0.1237 g	4.95
Volatile Solids (g/L)	Blank	0.025 L	0.0004 g	0.02
	1	0.025 L	0.1148 g	4.59
	LD 1	0.025 L	0.1167 g	4.68
COD (mg/L)	Standard (1000 mg/L)	1.00	1014	1014
	1	0.25	1160	4640
	2	0.25	1142	4568
SCOD (mg/L)	1	0.25	1047	4188
	LD 1	0.25	1077	4308
Total Phosphorus (mg/L P)	Standard (3.92 mg/L P)	0.20	0.65	3.25
	2	0.25	0.92	3.68
	LD 2	0.25	0.98	3.92
Ammonia (mg/L NH_4-N)	A&L			2.02
Nitrate + Nitrite (mg/L N)	A&L			0.68
TKN (mg/L N)	A&L			22
Sulfide (mg/L)	A&L			1
Sulfate (mg/L SO_4)	A&L			11

LD = Lab Duplicate

Note: sample 1 was un-preserved; sample 2 was preserved with H_2SO_4 to pH < 2.

Table B.4 Case C Manure Characterization Raw Data

Parameter	Sample No.	Dilution Factor	Original Reading	Reported Value	Reporting Limit
Total Solids (g/L)	Blank	See Case C Wastewater			
	1	0.025 L	0.6665 g	26.66	
Volatile Solids (g/L)	Blank	See Case C Wastewater			
	1	0.025 L	0.4111 g	16.44	
COD (mg/L)	Standard (a) (1000 mg/L)	1.0	1014	1014	
	1 (a)	0.04	563	14,075	
	1 (a)	0.02	637	31,850	
	LD 1 (a)	0.02	566	28,300	
	Standard (b) (1000 mg/L)	1.0	1024	1024	
	1 (b)	0.05	OL	OL	1500⁺
	LD1 (b)	0.05	1374	27,480	
	Standard (c) (1000 mg/L)	1.0	1019	1019	
	1 (c)	0.05	1382	27,640	
SCOD (mg/L)	1	0.05	537	10,740	
	LD 1	0.05	546	10,920	
Total Phosphorus (mg/L P)	Standard (3.92 mg/L P)	0.20	0.65	3.25	
	1	0.10	OL	OL	1.10⁺
	1	0.025	OL	OL	1.10⁺
Ammonia (mg/kg NH_4-N)	A&L			1004	
Nitrate (mg/kg N)	A&L			2	
TKN (mg/kg N)	A&L			1673	
Sulfide (mg/L)	A&L			3	
Sulfate (mg/L SO_4)	A&L			681	

LD = Lab Duplicate OL = Over Limit ⁺ Upper limit
(a), (b), (c) Corresponds given standard to sample(s).

APPENDIX C

CASE C SUBSTRATE ALLOCATION CALCULATIONS

The objective for Case C was to blend the cherry wastewater and dairy manure to an approximate COD/N of 100/4.5 (approximated from Bouallagui et al., 2004b). In this case, only SCOD was considered, representing substrate readily available to the microorganisms. TKN was considered for the nitrogen fraction, following Bouallagui et al. (2004b).

From the SCOD and TKN values given in Table 4.1, the COD:N ratios are:

Wastewater C (COD/N):	4248 / 23	=	100/0.517
Manure C (COD/N):	10830 / 1673	=	100/15.45

In the original blending calculations, the Wastewater C ratio was rounded to 100/0.52 and Manure C was rounded to 100/15.

A target of 1000 mg COD per flask was chosen to provide a significant net biogas volume when compared with the seed flask. To achieve an approximate ratio of 100/4.5 from a blended substrate would require 720 mg of Wastewater C and 280 mg of Manure C.

Wastewater: 720 mg COD *0.52 mg N /100 mg COD = 3.74 mg N

Manure: 280 mg COD *15 mg N / 100 mg COD = 42. mg N

Blended: (720 + 280) mg COD / (3.74 + 42.) mg N = 1000/45.74

COD/N = 100/4.57

To set up the respirometer flasks, the wastewater and manure was measured out volumetrically. The fractions of milligrams COD were simply converted to milliliters.

Wastewater: 720 mg COD / 4248 mg COD/L = 170 mL

Manure: 280 mg COD / 10,830 mg COD/L = 26 mL

The manure volume was rounded to 30 mL for ease of measurement. This provided a blended substrate volume of 200 mL. The remaining flask volume was then 450 mL. At a seed to nutrient solution of 4:1, this gave a seed volume of 90 mL and 360 mL of nutrient solution.

APPENDIX D

RESPIROMETER DATA

For Tables D.1 through D.8, the flask contents are abbreviated as follows: wastewater (W), manure (M), seed (S), nutrients (N), de-ionized water (DI) and replicate (rep). The 'Cumulative Gas' tables (Tables D.1, D.3, D.5 and D.7) contain data stored directly by the respirometer software. The 'Gas Rate' tables (Tables D.2, D.4, D.6 and D.8) contain the gas rate (mL/hr) calculated from the change in total gas (mL) over the given time count of three or four hours. While the respirometer software updates and plots the gas production rate every ten seconds, it does not store this data, so this had to be recalculated from the stored cumulative gas data which was recorded in multiple-hour time steps.

In Case A, the gas counter was reset at 13 hours when the water bath temperature and gas fluctuation had equilibrated, and data collection was changed from every 4 hours to every 3 hours. In Cases B-1, B-2 and C, the cumulative gas totals were recalculated after the acclimation period. This period was defined by a noted common decrease in the gas production rate consistent among all the flasks after an initial spike. Cumulative gas totals were recalculated from zero, and trial durations were retimed, starting at this point.

Table D.1 Respirometer Raw Data: Case A Cumulative Gas

		Cumulative Gas from Flasks (mL)							
Day	**Time (hrs)**	**WSN**	**½ (WSN)**	**S**	**WS (rep A)**	**WS (rep B)**	**WN**	**DI**	**Date**
	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4/5/07
	0	0.00	0.04	0.13	0.09	0.13	0.00	0.09	4/5/07
	4	9.38	7.55	9.28	10.37	11.23	5.28	8.31	4/6/07
	8	12.08	8.22	10.08	12.41	13.54	5.87	8.40	4/6/07
	12	14.19	8.58	11.77	14.54	15.85	5.96	8.58	4/6/07
	13	14.64	8.67	12.22	14.99	16.34	5.96	8.62	4/6/07
0.00	16	1.62	0.40	1.47	1.45	1.55	0.00	0.18	4/6/07
0.13	19	3.28	0.76	2.94	2.85	3.11	0.00	0.36	4/6/07
0.25	22	4.89	0.98	4.24	4.08	4.44	0.00	0.40	4/6/07
0.38	25	6.51	1.16	5.53	5.30	5.77	0.00	0.40	4/6/07
0.50	28	7.95	1.43	6.73	6.57	7.33	0.00	0.40	4/7/07
0.63	31	9.47	1.88	8.16	8.11	8.97	0.00	0.49	4/7/07
0.75	34	10.96	2.41	9.59	9.60	10.61	0.18	0.63	4/7/07
0.88	37	12.39	2.86	10.93	10.87	11.94	0.27	0.67	4/7/07
1.00	40	13.69	3.22	12.13	11.87	13.10	0.27	0.67	4/7/07
1.13	43	15.31	3.67	13.60	13.05	14.21	0.27	0.67	4/7/07
1.25	46	16.79	3.84	14.85	14.04	15.41	0.27	0.67	4/7/07
1.38	49	18.32	3.98	16.01	14.68	16.56	0.27	0.67	4/7/07
1.50	52	20.03	4.20	17.35	16.04	17.80	0.27	0.67	4/8/07
1.63	55	21.91	4.60	18.73	17.35	19.23	0.27	0.67	4/8/07
1.75	58	23.80	4.87	19.98	18.57	20.60	0.27	0.67	4/8/07
1.88	61	25.68	5.19	21.23	19.80	21.89	0.27	0.67	4/8/07
2.00	64	27.84	5.54	22.52	21.11	23.31	0.27	0.67	4/8/07
2.13	67	29.86	5.99	23.82	22.42	24.78	0.27	0.67	4/8/07
2.25	70	32.10	6.39	25.15	23.78	26.24	0.27	0.67	4/8/07
2.38	73	34.30	6.75	26.40	25.05	27.57	0.27	0.67	4/8/07
2.50	76	36.82	7.24	27.74	26.46	28.95	0.27	0.67	4/9/07
2.63	79	39.29	7.78	29.03	27.86	30.41	0.27	0.67	4/9/07
2.75	82	41.85	8.31	30.37	29.08	31.97	0.27	0.67	4/9/07
2.88	85	44.41	8.90	31.71	30.53	33.43	0.27	0.67	4/9/07
3.00	88	47.06	9.57	33.09	32.03	34.90	0.27	0.67	4/9/07
3.13	91	50.06	10.55	34.70	33.70	36.67	0.27	0.67	4/9/07
3.25	94	53.03	11.44	36.22	35.24	38.32	0.27	0.67	4/9/07
3.38	97	55.72	12.11	37.51	36.65	39.60	0.27	0.67	4/9/07
3.50	100	58.55	12.92	39.03	38.10	41.25	0.27	0.67	4/10/07
3.63	103	61.33	13.68	40.45	39.55	42.76	0.27	0.67	4/10/07
3.75	106	64.21	14.39	41.88	40.91	44.18	0.27	0.67	4/10/07
3.88	109	66.86	15.11	43.26	41.90	45.47	0.27	0.67	4/10/07
4.00	112	69.82	16.00	44.82	43.53	47.02	0.27	0.76	4/10/07
4.13	115	73.10	17.03	46.61	45.16	48.75	0.27	1.12	4/10/07
4.25	118	76.29	18.10	48.44	46.79	50.39	0.27	1.39	4/10/07
4.38	121	79.43	19.09	50.18	48.34	51.99	0.27	1.57	4/10/07
4.50	124	82.57	20.03	51.91	49.69	53.46	0.27	1.71	4/11/07

Table D.1 continued

4.63	127	86.03	21.14	53.88	51.32	55.19	0.27	2.02	4/11/07
4.75	130	89.53	22.26	55.88	52.87	56.61	0.27	2.25	4/11/07
4.88	133	93.21	23.47	58.07	54.54	58.30	0.27	2.56	4/11/07
5.00	136	97.34	24.99	60.52	56.44	60.25	0.27	3.10	4/11/07
5.13	139	101.56	26.51	62.93	58.35	62.25	1.05	3.64	4/11/07
5.25	142	105.65	27.89	65.34	60.11	64.11	1.55	4.09	4/11/07
5.38	145	109.96	29.32	67.75	61.88	65.89	1.96	4.49	4/11/07
5.50	148	114.41	30.80	70.29	63.65	67.80	2.46	4.98	4/12/07
5.63	151	118.76	32.14	72.74	65.32	69.49	2.78	5.25	4/12/07
5.75	154	122.85	33.35	75.11	66.77	70.55	2.87	5.34	4/12/07
5.88	157	126.62	34.33	77.29	68.00	72.11	2.87	5.34	4/12/07
6.00	160	130.48	35.49	79.66	69.40	73.53	2.87	5.34	4/12/07
6.13	163	134.25	36.56	82.02	70.62	74.86	2.87	5.34	4/12/07
6.25	166	137.89	37.59	84.38	71.85	76.15	2.87	5.34	4/12/07
6.38	169	141.61	38.75	86.79	73.11	77.48	2.87	5.34	4/12/07
6.50	172	145.70	40.19	89.56	74.61	79.21	2.87	5.34	4/13/07
6.63	175	149.83	41.62	92.41	76.19	80.99	2.87	5.34	4/13/07
6.75	178	154.01	43.09	95.27	77.73	82.67	2.87	5.34	4/13/07
6.88	181	158.23	44.61	98.12	79.32	84.36	2.87	5.34	4/13/07
7.00	184	162.94	46.35	101.29	81.18	86.36	2.87	5.34	4/13/07
7.13	187	168.06	48.37	104.85	83.31	88.36	2.87	5.34	4/13/07
7.25	190	172.51	50.24	108.47	85.48	90.89	2.87	5.34	4/13/07
7.38	193	177.62	52.08	112.08	87.52	93.20	2.87	5.34	4/13/07
7.50	196	183.15	54.13	115.96	89.88	95.77	2.87	5.34	4/14/07
7.63	199	188.80	56.32	119.97	92.37	98.43	2.87	5.34	4/14/07
7.75	202	194.46	58.56	124.03	94.86	101.14	2.87	5.34	4/14/07
7.88	205	200.16	60.84	128.18	97.35	103.94	2.87	5.34	4/14/07
8.00	208	205.87	63.07	132.37	100.02	106.78	2.87	5.34	4/14/07
8.13	211	212.06	65.80	137.10	103.24	110.20	2.87	5.34	4/14/07
8.25	214	217.94	68.26	141.56	106.23	113.31	2.87	5.34	4/14/07
8.38	217	223.60	70.58	146.02	109.22	116.15	2.87	5.34	4/14/07
8.50	220	229.39	73.00	150.66	112.30	119.39	2.87	5.34	4/15/07
8.63	223	234.83	75.41	155.30	115.38	122.59	2.87	5.34	4/15/07
8.75	226	240.66	77.82	160.02	118.50	126.05	2.87	5.34	4/15/07
8.88	229	246.37	80.15	164.71	121.63	129.29	2.87	5.34	4/15/07
9.00	232	252.29	82.56	169.48	124.94	132.93	2.87	5.70	4/15/07
9.13	235	258.44	85.15	174.61	128.52	136.75	3.64	6.47	4/15/07
9.25	238	264.60	87.57	179.60	132.05	140.39	4.14	6.96	4/15/07
9.38	241	270.70	89.80	184.42	135.49	143.99	4.46	7.23	4/15/07
9.50	244	277.03	92.13	189.33	138.98	147.72	4.82	7.54	4/16/07
9.63	247	283.63	94.59	194.41	142.69	151.49	5.19	7.95	4/16/07
9.75	250	290.28	96.95	199.32	146.27	155.31	5.46	8.17	4/16/07
9.88	253	297.10	99.41	204.40	149.99	159.31	5.73	8.49	4/16/07
10.00	256	304.11	101.96	208.33	153.61	163.48	6.10	8.85	4/16/07
10.13	259	311.43	104.69	212.83	157.69	168.01	6.60	9.34	4/16/07
10.25	262	318.92	107.41	217.51	161.77	172.45	6.96	9.70	4/16/07
10.38	265	326.24	110.01	221.89	165.71	176.76	7.14	9.88	4/16/07

Table D.1 continued

10.50	268	333.74	112.69	226.30	169.74	181.20	7.42	10.15	4/17/07
10.63	271	341.82	115.68	231.07	174.13	185.95	7.83	10.51	4/17/07
10.75	274	349.50	118.63	235.62	178.39	190.65	8.10	10.78	4/17/07
10.88	277	357.31	121.58	239.99	182.60	195.27	8.24	10.96	4/17/07
11.00	280	365.53	124.85	244.41	187.13	200.20	8.69	11.40	4/17/07
11.13	283	373.97	128.24	248.82	191.80	205.31	9.15	11.85	4/17/07
11.25	286	382.50	131.73	253.60	196.42	210.23	9.60	12.26	4/17/07
11.38	289	391.08	135.17	258.55	201.04	215.21	9.87	12.57	4/17/07
11.50	292	399.88	138.70	263.41	205.48	220.22	10.19	12.84	4/18/07
11.63	295	409.08	142.46	268.31	210.06	225.42	10.60	13.20	4/18/07
11.75	298	418.33	146.30	273.09	214.50	230.44	10.92	13.51	4/18/07
11.88	301	427.63	150.15	277.81	218.80	235.32	11.15	13.74	4/18/07
12.00	304	437.15	154.13	282.76	223.01	240.20	11.38	14.01	4/18/07
12.13	307	446.75	158.19	287.89	227.36	245.09	11.78	14.41	4/18/07
12.25	310	456.45	162.31	292.62	231.62	249.71	12.06	14.68	4/18/07
12.38	313	466.20	166.42	297.30	235.88	254.19	12.29	14.91	4/18/07
12.50	316	475.98	170.66	301.90	240.18	258.76	12.60	15.22	4/19/07
12.63	319	485.95	175.09	306.58	244.57	263.34	12.92	15.49	4/19/07
12.75	322	495.74	179.56	311.13	248.88	267.91	13.20	15.76	4/19/07
12.88	325	505.35	184.03	315.55	253.27	272.35	13.24	15.85	4/19/07
13.00	328	514.91	188.59	319.92	257.80	276.97	13.56	16.16	4/19/07
13.13	331	524.61	193.55	324.55	262.60	281.90	14.01	16.57	4/19/07
13.25	334	533.73	198.33	328.93	267.27	285.94	14.24	16.79	4/19/07
13.38	337	542.30	203.16	333.12	271.80	291.00	14.38	16.93	4/19/07
13.50	340	550.34	208.12	337.31	276.42	295.57	14.56	17.11	4/20/07
13.63	343	556.54	213.13	341.50	281.04	300.32	14.79	17.29	4/20/07
13.75	346	560.40	218.14	345.61	285.75	305.12	14.97	17.47	4/20/07
13.88	349	562.46	223.01	349.49	290.06	309.69	14.97	17.47	4/20/07
14.00	352	563.72	228.10	353.59	294.90	314.62	15.29	17.74	4/20/07
14.13	355	564.53	233.29	357.69	299.93	319.72	15.74	18.18	4/20/07
14.25	358	565.20	238.52	361.75	304.96	324.92	16.20	18.59	4/20/07
14.38	361	565.61	243.39	365.54	309.76	329.80	16.47	18.90	4/20/07
14.50	364	566.05	248.26	369.15	314.52	334.78	16.79	19.13	4/21/07
14.63	367	566.50	252.87	372.63	319.23	339.70	17.02	19.35	4/21/07
14.75	370	567.00	257.03	375.84	323.99	344.63	17.24	19.58	4/21/07
14.88	373	567.49	260.38	378.83	328.65	349.47	17.43	19.67	4/21/07
15.00	376	568.39	263.06	381.91	333.59	354.62	17.84	20.12	4/21/07
15.13	379	569.38	265.07	384.76	338.66	359.73	18.38	20.61	4/21/07
15.25	382	570.41	266.64	387.40	343.74	364.92	18.88	21.10	4/21/07
15.38	385	571.22	267.66	389.67	348.54	369.99	19.20	21.37	4/21/07
15.50	388	571.94	268.56	391.81	353.34	375.00	19.47	21.69	4/22/07
15.63	391	572.83	269.36	393.91	358.19	380.06	19.88	22.05	4/22/07
15.75	394	573.51	269.81	395.74	362.67	384.86	20.07	22.23	4/22/07
15.88	397	574.14	270.17	397.48	367.20	389.48	20.07	22.23	4/22/07
16.00	400	575.21	270.84	399.53	372.05	394.63	20.38	22.58	4/22/07
16.13	403	576.47	271.55	401.67	377.03	399.82	20.98	23.17	4/22/07
16.25	406	577.77	272.27	403.76	381.97	404.97	21.57	23.71	4/22/07

Table D.1 continued

16.38	409	578.94	272.71	405.64	386.64	409.86	21.89	24.02	4/22/07
16.50	412	580.11	273.07	407.47	391.12	414.25	22.25	24.34	4/23/07
16.63	415	581.59	273.56	409.43	395.79	419.09	22.70	24.78	4/23/07
16.75	418	583.03	274.06	411.44	400.32	424.02	23.21	25.19	4/23/07
16.88	421	584.01	274.32	413.17	404.62	428.46	23.30	25.37	4/23/07
17.00	424	584.96	274.64	415.05	408.92	432.99	23.66	25.68	4/23/07
17.13	427	585.36	274.73	416.61	412.86	437.03	23.75	25.82	4/23/07
17.25	430	585.36	274.73	418.08	416.53	440.80	23.75	25.82	4/23/07
17.38	433	585.36	274.73	419.37	419.89	444.27	23.75	25.82	4/23/07
17.50	436	585.36	274.73	420.80	423.19	447.77	23.75	25.82	4/24/07
17.63	439	585.36	274.73	422.36	426.50	451.19	23.75	25.82	4/24/07
17.75	442	585.36	274.73	423.97	429.58	454.35	23.75	25.82	4/24/07
17.88	445	585.36	274.73	425.48	432.39	457.32	23.75	25.82	4/24/07
18.00	448	585.36	274.73	427.18	435.11	460.25	23.75	25.82	4/24/07
18.13	451	585.41	274.73	428.96	437.64	462.96	23.75	25.82	4/24/07
18.25	454	585.54	274.73	430.79	439.95	465.40	23.75	25.82	4/24/07
18.38	457	585.59	274.73	432.53	442.04	467.53	23.75	25.82	4/24/07
18.50	460	585.59	274.73	434.18	443.94	469.62	23.75	25.82	4/25/07
18.63	463	585.59	274.73	435.92	445.89	471.66	23.75	25.82	4/25/07
18.75	466	585.59	274.73	437.66	447.79	473.66	23.75	25.82	4/25/07
18.88	469	585.59	274.73	439.27	449.47	475.39	23.75	25.82	4/25/07
19.00	472	585.59	274.73	441.09	451.41	477.48	23.75	25.82	4/25/07
19.13	475	585.63	274.73	442.7	453.09	479.25	23.75	25.82	4/25/07
19.25	478	585.63	274.73	444.35	454.81	481.03	23.75	25.82	4/25/07
19.38	481	585.63	274.73	445.91	456.44	482.76	23.75	25.82	4/25/07
19.50	484	585.63	274.73	447.74	458.3	484.71	23.75	25.82	4/26/07
19.63	487	585.72	274.73	449.48	460.2	486.71	24.02	26.04	4/26/07
19.75	490	585.90	274.73	451.22	462.06	488.67	24.48	26.49	4/26/07
19.88	493	585.99	274.73	452.91	463.78	490.62	24.89	26.9	4/26/07
20.00	496	586.12	274.73	454.65	465.64	492.66	25.34	27.34	4/26/07
20.13	499	586.30	274.73	456.35	467.54	494.66	25.8	27.75	4/26/07
20.25	502	586.39	274.73	458.04	469.4	496.7	26.21	28.11	4/26/07
20.38	505	586.48	274.73	459.42	471.26	498.66	26.57	28.47	4/26/07
20.50	508	586.66	274.73	461.12	473.16	500.7	26.98	28.83	4/27/07
20.63	511	586.75	274.73	462.68	474.97	502.47	27.25	29.1	4/27/07
20.75	514	586.80	274.73	464.11	476.65	504.3	27.44	29.23	4/27/07
20.88	517	586.80	274.73	465.31	478.19	505.76	27.44	29.23	4/27/07
21.00	520	586.80	274.73	466.56	479.68	507.36	27.44	29.23	4/27/07
21.13	523	586.80	274.73	467.76	481.22	509	27.44	29.23	4/27/07
21.25	526	586.80	274.73	468.97	482.81	510.64	27.44	29.23	4/27/07
21.38	529	586.80	274.73	470.13	484.35	512.24	27.44	29.23	4/27/07
21.50	532	586.80	274.73	471.38	485.98	513.97	27.44	29.23	4/28/07
21.63	535	586.80	274.73	472.67	487.7	515.66	27.44	29.23	4/28/07
21.75	538	586.80	274.73	473.88	489.38	517.48	27.44	29.23	4/28/07
21.88	541	586.80	274.73	474.99	491.01	519.17	27.44	29.23	4/28/07
22.00	544	586.80	274.73	476.24	492.77	520.95	27.44	29.23	4/28/07
22.13	547	586.93	274.73	477.58	494.59	522.9	27.44	29.23	4/28/07

Table D.1 continued

22.25	550	587.02	274.73	478.78	496.31	524.63	27.44	29.23	4/28/07
22.38	553	587.07	274.73	479.9	497.89	526.27	27.44	29.23	4/28/07
22.50	556	587.07	274.86	480.88	499.25	527.74	27.44	29.23	4/29/07
22.63	559	587.07	274.86	481.86	500.7	529.25	27.44	29.23	4/29/07
22.75	562	587.07	274.86	482.88	502.15	530.76	27.44	29.23	4/29/07
22.88	565	587.07	274.86	483.78	503.51	532.09	27.44	29.23	4/29/07
23.00	568	587.29	274.86	484.94	505.14	533.73	27.44	29.23	4/29/07
23.13	571	587.74	274.86	486.36	507.04	535.77	27.44	29.23	4/29/07
23.25	574	588.37	274.99	487.75	508.99	537.82	27.66	29.23	4/29/07
23.38	577	588.86	274.99	488.99	510.8	539.73	28.16	29.23	4/29/07
23.50	580	589.45	274.99	490.24	512.57	541.68	28.71	29.32	4/30/07
23.63	583	589.54	275.04	490.91	513.75	542.88	28.71	29.36	4/30/07
23.75	586	589.76	275.04	491.72	515.02	544.21	28.71	29.36	4/30/07
23.88	589	590.12	275.04	492.52	516.33	545.41	28.71	29.36	4/30/07
24.00	592	590.66	275.04	493.45	517.73	546.96	28.71	29.36	4/30/07
24.13	595	591.38	275.04	494.52	519.36	548.74	28.71	29.36	4/30/07
24.25	598	592.19	275.04	495.68	521.09	550.56	28.71	29.36	4/30/07
24.38	601	592.72	275.04	496.44	522.35	551.85	28.71	29.36	4/30/07
24.50	604	593.62	275.04	497.56	524.03	553.76	28.76	29.36	5/1/07
24.63	607	594.52	275.04	498.67	525.75	555.53	29.3	29.36	5/1/07
24.75	610	595.19	275.04	499.56	527.29	557.13	29.53	29.36	5/1/07
24.88	613	595.82	275.04	500.37	528.74	558.64	29.67	29.36	5/1/07
25.00	616	596.95	275.04	501.3	530.46	560.59	30.17	29.41	5/1/07
25.13	619	597.93	275.13	502.46	532.18	562.46	30.62	29.86	5/1/07
25.25	622	598.74	275.13	503.49	533.82	564.19	30.99	30.13	5/1/07
25.38	625	599.15	275.35	504.16	535.13	565.52	31.03	30.17	5/1/07
25.50	628	599.64	275.35	504.92	536.53	566.99	31.21	30.17	5/2/07
25.63	631	599.95	275.35	505.59	537.85	568.45	31.35	30.17	5/2/07
25.75	634	600.18	275.35	506.17	539.16	569.83	31.44	30.17	5/2/07
25.88	637	600.27	275.35	506.66	540.38	571.07	31.44	30.17	5/2/07
26.00	640	600.36	275.35	507.24	541.74	572.45	31.49	30.17	5/2/07
26.13	643	600.72	275.35	507.86	543.19	574	31.71	30.17	5/2/07
26.25	646	601.03	275.35	508.48	544.69	575.6	32.03	30.17	5/2/07
26.38	649	601.12	275.35	508.93	546	576.67	32.08	30.17	5/2/07
26.50	652	601.17	275.35	509.38	547.36	578.31	32.31	30.17	5/3/07
26.63	655	601.17	275.35	509.78	548.72	579.86	32.53	30.17	5/3/07
26.75	658	601.17	275.35	510.09	550.12	581.33	32.76	30.17	5/3/07
26.88	661	601.17	275.35	510.27	551.21	582.66	32.85	30.17	5/3/07
27.00	664	601.17	275.35	510.58	552.8	584.17	33.17	30.17	5/3/07
27.13	667	601.26	275.35	510.94	554.38	585.86	33.58	30.17	5/3/07
27.25	670	601.35	275.35	511.25	555.92	587.55	33.99	30.17	5/3/07
27.38	673	601.39	275.35	511.38	557.33	588.97	34.22	30.17	5/3/07
27.50	676	601.39	275.35	511.43	558.59	590.34	34.49	30.17	5/4/07
27.63	679	601.39	275.35	511.47	560	591.85	34.81	30.17	5/4/07
27.75	682	601.44	275.35	511.52	561.4	593.36	35.13	30.17	5/4/07
27.88	685	601.44	275.35	511.52	562.67	594.65	35.31	30.17	5/4/07
28.00	688	601.44	275.35	511.56	564.03	595.76	35.72	30.17	5/4/07

Table D.1 continued

28.13	691	601.62	275.53	511.7	565.71	597.45	36.31	30.17	5/4/07
28.25	694	601.70	275.53	511.96	567.2	599	36.76	30.17	5/4/07
28.38	697	601.84	275.53	512.01	568.65	600.33	37.04	30.17	5/4/07
28.50	700	601.84	275.53	512.01	569.92	601.66	37.36	30.17	5/5/07
28.63	703	601.84	275.53	512.01	571.28	603.09	37.72	30.17	5/5/07
28.75	706	601.93	275.53	512.01	572.59	604.42	38.08	30.17	5/5/07
28.88	709	601.93	275.53	512.01	573.77	605.44	38.31	30.17	5/5/07
29.00	712	601.93	275.53	512.01	575.04	606.64	38.58	30.17	5/5/07
29.13	715	601.93	275.58	512.01	576.17	607.75	38.86	30.17	5/5/07
29.25	718	601.93	275.75	512.01	577.21	608.77	39.04	30.17	5/5/07
29.38	721	601.93	275.75	512.01	578.16	609.66	39.18	30.17	5/5/07
29.50	724	601.93	275.75	512.01	579.02	610.41	39.22	30.17	5/6/07
29.63	727	601.93	275.75	512.01	579.84	611.08	39.31	30.17	5/6/07
29.75	730	601.93	275.75	512.01	580.93	612.05	39.68	30.17	5/6/07
29.88	733	601.93	275.75	512.01	581.65	612.45	39.72	30.17	5/6/07
30.00	736	601.93	275.75	512.01	582.65	613.25	39.9	30.17	5/6/07
30.13	739	601.93	275.75	512.01	583.74	614.14	40.36	30.17	5/6/07
30.25	742	601.93	275.75	512.01	584.82	614.94	40.81	30.17	5/6/07
30.38	745	601.93	275.75	512.01	585.73	615.43	41.04	30.17	5/6/07
30.50	748	601.97	275.75	512.01	586.32	616.01	41.5	30.17	5/7/07
30.63	751	602.15	275.75	512.01	587.36	616.49	41.86	30.17	5/7/07
30.75	754	602.33	275.75	512.01	588.13	616.94	42.22	30.17	5/7/07
30.88	757	602.33	275.75	512.01	588.54	616.98	42.22	30.17	5/7/07
31.00	760	602.47	275.75	512.01	589.22	617.43	42.68	30.17	5/7/07
31.13	763	602.78	275.75	512.01	590.03	617.91	43.22	30.17	5/7/07
31.25	766	603.05	275.75	512.01	590.62	618.27	43.68	30.17	5/7/07
31.38	769	603.28	275.75	512.01	591.07	618.49	44	30.17	5/7/07
31.50	772	603.37	275.75	512.01	591.35	618.54	44.27	30.17	5/8/07
31.63	775	603.50	275.75	512.01	591.71	618.58	44.64	30.31	5/8/07
31.75	778	603.73	275.75	512.01	591.89	618.85	44.82	30.44	5/8/07
31.88	781	603.73	275.75	512.01	591.94	618.85	44.82	30.44	5/8/07
32.00	784	603.73	275.75	512.01	592.03	618.85	44.95	30.44	5/8/07
32.13	787	603.95	275.75	512.01	592.21	618.85	45.23	30.67	5/8/07
32.25	790	604.22	275.75	512.01	592.3	618.85	45.5	30.89	5/8/07
32.38	793	604.31	275.75	512.01	592.3	618.85	45.59	30.94	5/8/07
32.50	796	604.31	275.75	512.01	592.3	618.85	45.59	30.94	5/9/07
32.63	799	604.49	275.75	512.01	592.3	618.85	45.77	31.07	5/9/07
32.75	802	604.67	275.75	512.01	592.3	618.85	45.82	31.21	5/9/07
32.88	805	604.67	275.75	512.01	592.3	618.85	45.82	31.21	5/9/07
33.00	808	604.71	275.75	512.01	592.3	618.85	45.82	31.21	5/9/07
33.13	811	604.80	275.75	512.01	592.3	618.85	45.82	31.21	5/9/07
33.25	814	604.98	275.75	512.01	592.3	618.85	45.82	31.21	5/9/07
33.38	817	605.21	275.75	512.01	592.3	618.85	45.82	31.21	5/9/07
33.50	820	605.30	275.75	512.01	592.3	618.85	45.82	31.21	5/10/07
33.63	823	605.48	275.75	512.01	592.3	618.85	45.82	31.21	5/10/07
33.75	826	605.57	275.75	512.01	592.3	618.85	45.82	31.21	5/10/07
33.88	829	605.70	275.75	512.01	592.3	618.85	45.82	31.21	5/10/07

Table D.2 Respirometer Calculated Data: Case A Gas Production Rate

		Gas Production Rate (mL/hr)						
Day	**Time (hrs)**	**WSN**	**½ (WSN)**	**S**	**WS (rep A)**	**WS (rep B)**	**WN**	**DI**
	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0	0.00	0.04	0.13	0.09	0.13	0.00	0.09
	4	2.34	1.88	2.29	2.57	2.77	1.32	2.05
	8	0.68	0.17	0.20	0.51	0.58	0.15	0.02
	12	0.53	0.09	0.42	0.53	0.58	0.02	0.04
	13	0.47	0.09	0.47	0.47	0.51	0.00	0.04
0.00	16	0.54	0.13	0.49	0.48	0.52	0.00	0.06
0.13	19	0.55	0.12	0.49	0.47	0.52	0.00	0.06
0.25	22	0.54	0.07	0.43	0.41	0.44	0.00	0.01
0.38	25	0.54	0.06	0.43	0.41	0.44	0.00	0.00
0.50	28	0.48	0.09	0.40	0.42	0.52	0.00	0.00
0.63	31	0.51	0.15	0.48	0.51	0.55	0.00	0.03
0.75	34	0.50	0.18	0.48	0.50	0.55	0.06	0.05
0.88	37	0.48	0.15	0.45	0.42	0.44	0.03	0.01
1.00	40	0.43	0.12	0.40	0.33	0.39	0.00	0.00
1.13	43	0.54	0.15	0.49	0.39	0.37	0.00	0.00
1.25	46	0.49	0.06	0.42	0.33	0.40	0.00	0.00
1.38	49	0.51	0.05	0.39	0.21	0.38	0.00	0.00
1.50	52	0.57	0.07	0.45	0.45	0.41	0.00	0.00
1.63	55	0.63	0.13	0.46	0.44	0.48	0.00	0.00
1.75	58	0.63	0.09	0.42	0.41	0.46	0.00	0.00
1.88	61	0.63	0.11	0.42	0.41	0.43	0.00	0.00
2.00	64	0.72	0.12	0.43	0.44	0.47	0.00	0.00
2.13	67	0.67	0.15	0.43	0.44	0.49	0.00	0.00
2.25	70	0.75	0.13	0.44	0.45	0.49	0.00	0.00
2.38	73	0.73	0.12	0.42	0.42	0.44	0.00	0.00
2.50	76	0.84	0.16	0.45	0.47	0.46	0.00	0.00
2.63	79	0.82	0.18	0.43	0.47	0.49	0.00	0.00
2.75	82	0.85	0.18	0.45	0.41	0.52	0.00	0.00
2.88	85	0.85	0.20	0.45	0.48	0.49	0.00	0.00
3.00	88	0.89	0.22	0.46	0.50	0.49	0.00	0.00
3.13	91	1.00	0.33	0.54	0.56	0.59	0.00	0.00
3.25	94	0.99	0.30	0.51	0.51	0.55	0.00	0.00
3.38	97	0.90	0.22	0.43	0.47	0.43	0.00	0.00
3.50	100	0.94	0.27	0.51	0.48	0.55	0.00	0.00
3.63	103	0.93	0.25	0.47	0.48	0.50	0.00	0.00
3.75	106	0.96	0.24	0.48	0.45	0.47	0.00	0.00
3.88	109	0.88	0.24	0.46	0.33	0.43	0.00	0.00
4.00	112	0.99	0.30	0.52	0.54	0.52	0.00	0.03
4.13	115	1.09	0.34	0.60	0.54	0.58	0.00	0.12
4.25	118	1.06	0.36	0.61	0.54	0.55	0.00	0.09
4.38	121	1.05	0.33	0.58	0.52	0.53	0.00	0.06

Table D.2 continued

4.50	124	1.05	0.31	0.58	0.45	0.49	0.00	0.05
4.63	127	1.15	0.37	0.66	0.54	0.58	0.00	0.10
4.75	130	1.17	0.37	0.67	0.52	0.47	0.00	0.08
4.88	133	1.23	0.40	0.73	0.56	0.56	0.00	0.10
5.00	136	1.38	0.51	0.82	0.63	0.65	0.00	0.18
5.13	139	1.41	0.51	0.80	0.64	0.67	0.26	0.18
5.25	142	1.36	0.46	0.80	0.59	0.62	0.17	0.15
5.38	145	1.44	0.48	0.80	0.59	0.59	0.14	0.13
5.50	148	1.48	0.49	0.85	0.59	0.64	0.17	0.16
5.63	151	1.45	0.45	0.82	0.56	0.56	0.11	0.09
5.75	154	1.36	0.40	0.79	0.48	0.35	0.03	0.03
5.88	157	1.26	0.33	0.73	0.41	0.52	0.00	0.00
6.00	160	1.29	0.39	0.79	0.47	0.47	0.00	0.00
6.13	163	1.26	0.36	0.79	0.41	0.44	0.00	0.00
6.25	166	1.21	0.34	0.79	0.41	0.43	0.00	0.00
6.38	169	1.24	0.39	0.80	0.42	0.44	0.00	0.00
6.50	172	1.36	0.48	0.92	0.50	0.58	0.00	0.00
6.63	175	1.38	0.48	0.95	0.53	0.59	0.00	0.00
6.75	178	1.39	0.49	0.95	0.51	0.56	0.00	0.00
6.88	181	1.41	0.51	0.95	0.53	0.56	0.00	0.00
7.00	184	1.57	0.58	1.06	0.62	0.67	0.00	0.00
7.13	187	1.72	0.68	1.19	0.71	0.67	0.00	0.00
7.25	190	1.48	0.62	1.21	0.72	0.84	0.00	0.00
7.38	193	1.70	0.61	1.20	0.68	0.77	0.00	0.00
7.50	196	1.84	0.68	1.29	0.79	0.86	0.00	0.00
7.63	199	1.88	0.73	1.34	0.83	0.89	0.00	0.00
7.75	202	1.89	0.75	1.35	0.83	0.90	0.00	0.00
7.88	205	1.90	0.76	1.38	0.83	0.93	0.00	0.00
8.00	208	1.90	0.74	1.40	0.89	0.95	0.00	0.00
8.13	211	2.06	0.91	1.58	1.07	1.14	0.00	0.00
8.25	214	1.96	0.82	1.49	1.00	1.04	0.00	0.00
8.38	217	1.89	0.77	1.49	1.00	0.95	0.00	0.00
8.50	220	1.93	0.81	1.55	1.03	1.08	0.00	0.00
8.63	223	1.81	0.80	1.55	1.03	1.07	0.00	0.00
8.75	226	1.94	0.80	1.57	1.04	1.15	0.00	0.00
8.88	229	1.90	0.78	1.56	1.04	1.08	0.00	0.00
9.00	232	1.97	0.80	1.59	1.10	1.21	0.00	0.12
9.13	235	2.05	0.86	1.71	1.19	1.27	0.26	0.26
9.25	238	2.05	0.81	1.66	1.18	1.21	0.17	0.16
9.38	241	2.03	0.74	1.61	1.15	1.20	0.11	0.09
9.50	244	2.11	0.78	1.64	1.16	1.24	0.12	0.10
9.63	247	2.20	0.82	1.69	1.24	1.26	0.12	0.14
9.75	250	2.22	0.79	1.64	1.19	1.27	0.09	0.07
9.88	253	2.27	0.82	1.69	1.24	1.33	0.09	0.11
10.00	256	2.34	0.85	1.31	1.21	1.39	0.12	0.12

Table D.2 continued

10.13	259	2.44	0.91	1.50	1.36	1.51	0.17	0.16
10.25	262	2.50	0.91	1.56	1.36	1.48	0.12	0.12
10.38	265	2.44	0.87	1.46	1.31	1.44	0.06	0.06
10.50	268	2.50	0.89	1.47	1.34	1.48	0.09	0.09
10.63	271	2.69	1.00	1.59	1.46	1.58	0.14	0.12
10.75	274	2.56	0.98	1.52	1.42	1.57	0.09	0.09
10.88	277	2.60	0.98	1.46	1.40	1.54	0.05	0.06
11.00	280	2.74	1.09	1.47	1.51	1.64	0.15	0.15
11.13	283	2.81	1.13	1.47	1.56	1.70	0.15	0.15
11.25	286	2.86	1.17	1.60	1.55	1.65	0.15	0.14
11.38	289	2.86	1.15	1.65	1.54	1.66	0.09	0.10
11.50	292	2.93	1.18	1.62	1.48	1.67	0.11	0.09
11.63	295	3.07	1.25	1.63	1.53	1.73	0.14	0.12
11.75	298	3.08	1.28	1.59	1.48	1.67	0.11	0.10
11.88	301	3.10	1.28	1.57	1.43	1.63	0.08	0.08
12.00	304	3.17	1.33	1.65	1.40	1.63	0.08	0.09
12.13	307	3.20	1.35	1.71	1.45	1.63	0.13	0.13
12.25	310	3.23	1.37	1.58	1.42	1.54	0.09	0.09
12.38	313	3.25	1.37	1.56	1.42	1.49	0.08	0.08
12.50	316	3.26	1.41	1.53	1.43	1.52	0.10	0.10
12.63	319	3.32	1.48	1.56	1.46	1.53	0.11	0.09
12.75	322	3.26	1.49	1.52	1.44	1.52	0.09	0.09
12.88	325	3.20	1.49	1.47	1.46	1.48	0.01	0.03
13.00	328	3.19	1.52	1.46	1.51	1.54	0.11	0.10
13.13	331	3.23	1.65	1.54	1.60	1.64	0.15	0.14
13.25	334	3.04	1.59	1.46	1.56	1.35	0.08	0.07
13.38	337	2.86	1.61	1.40	1.51	1.69	0.05	0.05
13.50	340	2.68	1.65	1.40	1.54	1.52	0.06	0.06
13.63	343	2.07	1.67	1.40	1.54	1.58	0.08	0.06
13.75	346	1.29	1.67	1.37	1.57	1.60	0.06	0.06
13.88	349	0.69	1.62	1.29	1.44	1.52	0.00	0.00
14.00	352	0.42	1.70	1.37	1.61	1.64	0.11	0.09
14.13	355	0.27	1.73	1.37	1.68	1.70	0.15	0.15
14.25	358	0.22	1.74	1.35	1.68	1.73	0.15	0.14
14.38	361	0.14	1.62	1.26	1.60	1.63	0.09	0.10
14.50	364	0.15	1.62	1.20	1.59	1.66	0.11	0.08
14.63	367	0.15	1.54	1.16	1.57	1.64	0.08	0.07
14.75	370	0.17	1.39	1.07	1.59	1.64	0.07	0.08
14.88	373	0.16	1.12	1.00	1.55	1.61	0.06	0.03
15.00	376	0.30	0.89	1.03	1.65	1.72	0.14	0.15
15.13	379	0.33	0.67	0.95	1.69	1.70	0.18	0.16
15.25	382	0.34	0.52	0.88	1.69	1.73	0.17	0.16
15.38	385	0.27	0.34	0.76	1.61	1.70	0.11	0.09
15.50	388	0.24	0.30	0.71	1.60	1.67	0.09	0.11
15.63	391	0.30	0.27	0.70	1.62	1.69	0.14	0.12
15.75	394	0.23	0.15	0.61	1.49	1.60	0.06	0.06
15.88	397	0.21	0.12	0.58	1.51	1.54	0.00	0.00

Table D.2 continued

10.13	259	2.44	0.91	1.50	1.36	1.51	0.17	0.16
10.25	262	2.50	0.91	1.56	1.36	1.48	0.12	0.12
10.38	265	2.44	0.87	1.46	1.31	1.44	0.06	0.06
10.50	268	2.50	0.89	1.47	1.34	1.48	0.09	0.09
10.63	271	2.69	1.00	1.59	1.46	1.58	0.14	0.12
10.75	274	2.56	0.98	1.52	1.42	1.57	0.09	0.09
10.88	277	2.60	0.98	1.46	1.40	1.54	0.05	0.06
11.00	280	2.74	1.09	1.47	1.51	1.64	0.15	0.15
11.13	283	2.81	1.13	1.47	1.56	1.70	0.15	0.15
11.25	286	2.86	1.17	1.60	1.55	1.65	0.15	0.14
11.38	289	2.86	1.15	1.65	1.54	1.66	0.09	0.10
11.50	292	2.93	1.18	1.62	1.48	1.67	0.11	0.09
11.63	295	3.07	1.25	1.63	1.53	1.73	0.14	0.12
11.75	298	3.08	1.28	1.59	1.48	1.67	0.11	0.10
11.88	301	3.10	1.28	1.57	1.43	1.63	0.08	0.08
12.00	304	3.17	1.33	1.65	1.40	1.63	0.08	0.09
12.13	307	3.20	1.35	1.71	1.45	1.63	0.13	0.13
12.25	310	3.23	1.37	1.58	1.42	1.54	0.09	0.09
12.38	313	3.25	1.37	1.56	1.42	1.49	0.08	0.08
12.50	316	3.26	1.41	1.53	1.43	1.52	0.10	0.10
12.63	319	3.32	1.48	1.56	1.46	1.53	0.11	0.09
12.75	322	3.26	1.49	1.52	1.44	1.52	0.09	0.09
12.88	325	3.20	1.49	1.47	1.46	1.48	0.01	0.03
13.00	328	3.19	1.52	1.46	1.51	1.54	0.11	0.10
13.13	331	3.23	1.65	1.54	1.60	1.64	0.15	0.14
13.25	334	3.04	1.59	1.46	1.56	1.35	0.08	0.07
13.38	337	2.86	1.61	1.40	1.51	1.69	0.05	0.05
13.50	340	2.68	1.65	1.40	1.54	1.52	0.06	0.06
13.63	343	2.07	1.67	1.40	1.54	1.58	0.08	0.06
13.75	346	1.29	1.67	1.37	1.57	1.60	0.06	0.06
13.88	349	0.69	1.62	1.29	1.44	1.52	0.00	0.00
14.00	352	0.42	1.70	1.37	1.61	1.64	0.11	0.09
14.13	355	0.27	1.73	1.37	1.68	1.70	0.15	0.15
14.25	358	0.22	1.74	1.35	1.68	1.73	0.15	0.14
14.38	361	0.14	1.62	1.26	1.60	1.63	0.09	0.10
14.50	364	0.15	1.62	1.20	1.59	1.66	0.11	0.08
14.63	367	0.15	1.54	1.16	1.57	1.64	0.08	0.07
14.75	370	0.17	1.39	1.07	1.59	1.64	0.07	0.08
14.88	373	0.16	1.12	1.00	1.55	1.61	0.06	0.03
15.00	376	0.30	0.89	1.03	1.65	1.72	0.14	0.15
15.13	379	0.33	0.67	0.95	1.69	1.70	0.18	0.16
15.25	382	0.34	0.52	0.88	1.69	1.73	0.17	0.16
15.38	385	0.27	0.34	0.76	1.61	1.70	0.11	0.09
15.50	388	0.24	0.30	0.71	1.60	1.67	0.09	0.11
15.63	391	0.30	0.27	0.70	1.62	1.69	0.14	0.12
15.75	394	0.23	0.15	0.61	1.49	1.60	0.06	0.06
15.88	397	0.21	0.12	0.58	1.51	1.54	0.00	0.00

Table D.2 continued

21.88	541	0.00	0.00	0.37	0.54	0.56	0.00	0.00
22.00	544	0.00	0.00	0.42	0.59	0.59	0.00	0.00
22.13	547	0.04	0.00	0.45	0.61	0.65	0.00	0.00
22.25	550	0.03	0.00	0.40	0.57	0.58	0.00	0.00
22.38	553	0.02	0.00	0.37	0.53	0.55	0.00	0.00
22.50	556	0.00	0.04	0.33	0.45	0.49	0.00	0.00
22.63	559	0.00	0.00	0.33	0.48	0.50	0.00	0.00
22.75	562	0.00	0.00	0.34	0.48	0.50	0.00	0.00
22.88	565	0.00	0.00	0.30	0.45	0.44	0.00	0.00
23.00	568	0.07	0.00	0.39	0.54	0.55	0.00	0.00
23.13	571	0.15	0.00	0.47	0.63	0.68	0.00	0.00
23.25	574	0.21	0.04	0.46	0.65	0.68	0.07	0.00
23.38	577	0.16	0.00	0.41	0.60	0.64	0.17	0.00
23.50	580	0.20	0.00	0.42	0.59	0.65	0.18	0.03
23.63	583	0.03	0.02	0.22	0.40	0.40	0.00	0.01
23.75	586	0.07	0.00	0.27	0.42	0.44	0.00	0.00
23.88	589	0.12	0.00	0.27	0.44	0.40	0.00	0.00
24.00	592	0.18	0.00	0.31	0.47	0.52	0.00	0.00
24.13	595	0.24	0.00	0.36	0.54	0.59	0.00	0.00
24.25	598	0.27	0.00	0.39	0.58	0.61	0.00	0.00
24.38	601	0.18	0.00	0.25	0.42	0.43	0.00	0.00
24.50	604	0.30	0.00	0.37	0.56	0.64	0.02	0.00
24.63	607	0.30	0.00	0.37	0.57	0.59	0.18	0.00
24.75	610	0.22	0.00	0.30	0.51	0.53	0.08	0.00
24.88	613	0.21	0.00	0.27	0.48	0.50	0.05	0.00
25.00	616	0.38	0.00	0.31	0.57	0.65	0.17	0.02
25.13	619	0.33	0.03	0.39	0.57	0.62	0.15	0.15
25.25	622	0.27	0.00	0.34	0.55	0.58	0.12	0.09
25.38	625	0.14	0.07	0.22	0.44	0.44	0.01	0.01
25.50	628	0.16	0.00	0.25	0.47	0.49	0.06	0.00
25.63	631	0.10	0.00	0.22	0.44	0.49	0.05	0.00
25.75	634	0.08	0.00	0.19	0.44	0.46	0.03	0.00
25.88	637	0.03	0.00	0.16	0.41	0.41	0.00	0.00
26.00	640	0.03	0.00	0.19	0.45	0.46	0.02	0.00
26.13	643	0.12	0.00	0.21	0.48	0.52	0.07	0.00
26.25	646	0.10	0.00	0.21	0.50	0.53	0.11	0.00
26.38	649	0.03	0.00	0.15	0.44	0.36	0.02	0.00
26.50	652	0.02	0.00	0.15	0.45	0.55	0.08	0.00
26.63	655	0.00	0.00	0.13	0.45	0.52	0.07	0.00
26.75	658	0.00	0.00	0.10	0.47	0.49	0.08	0.00
26.88	661	0.00	0.00	0.06	0.36	0.44	0.03	0.00
27.00	664	0.00	0.00	0.10	0.53	0.50	0.11	0.00
27.13	667	0.03	0.00	0.12	0.53	0.57	0.14	0.00
27.25	670	0.03	0.00	0.10	0.51	0.56	0.14	0.00
27.38	673	0.01	0.00	0.04	0.47	0.47	0.08	0.00
27.50	676	0.00	0.00	0.02	0.42	0.46	0.09	0.00
27.63	679	0.00	0.00	0.01	0.47	0.50	0.11	0.00

Table D.2 continued

16.00	400	0.36	0.22	0.68	1.62	1.72	0.10	0.12
16.13	403	0.42	0.24	0.71	1.66	1.73	0.20	0.20
16.25	406	0.43	0.24	0.70	1.65	1.72	0.20	0.18
16.38	409	0.39	0.15	0.63	1.56	1.63	0.11	0.10
16.50	412	0.39	0.12	0.61	1.49	1.46	0.12	0.11
16.63	415	0.49	0.16	0.65	1.56	1.61	0.15	0.15
16.75	418	0.48	0.17	0.67	1.51	1.64	0.17	0.14
16.88	421	0.33	0.09	0.58	1.43	1.48	0.03	0.06
17.00	424	0.32	0.11	0.63	1.43	1.51	0.12	0.10
17.13	427	0.13	0.03	0.52	1.31	1.35	0.03	0.05
17.25	430	0.00	0.00	0.49	1.22	1.26	0.00	0.00
17.38	433	0.00	0.00	0.43	1.12	1.16	0.00	0.00
17.50	436	0.00	0.00	0.48	1.10	1.17	0.00	0.00
17.63	439	0.00	0.00	0.52	1.10	1.14	0.00	0.00
17.75	442	0.00	0.00	0.54	1.03	1.05	0.00	0.00
17.88	445	0.00	0.00	0.50	0.94	0.99	0.00	0.00
18.00	448	0.00	0.00	0.57	0.91	0.98	0.00	0.00
18.13	451	0.02	0.00	0.59	0.84	0.90	0.00	0.00
18.25	454	0.04	0.00	0.61	0.77	0.81	0.00	0.00
18.38	457	0.02	0.00	0.58	0.70	0.71	0.00	0.00
18.50	460	0.00	0.00	0.55	0.63	0.70	0.00	0.00
18.63	463	0.00	0.00	0.58	0.65	0.68	0.00	0.00
18.75	466	0.00	0.00	0.58	0.63	0.67	0.00	0.00
18.88	469	0.00	0.00	0.54	0.56	0.58	0.00	0.00
19.00	472	0.00	0.00	0.61	0.65	0.70	0.00	0.00
19.13	475	0.01	0.00	0.54	0.56	0.59	0.00	0.00
19.25	478	0.00	0.00	0.55	0.57	0.59	0.00	0.00
19.38	481	0.00	0.00	0.52	0.54	0.58	0.00	0.00
19.50	484	0.00	0.00	0.61	0.62	0.65	0.00	0.00
19.63	487	0.03	0.00	0.58	0.63	0.67	0.09	0.07
19.75	490	0.06	0.00	0.58	0.62	0.65	0.15	0.15
19.88	493	0.03	0.00	0.56	0.57	0.65	0.14	0.14
20.00	496	0.04	0.00	0.58	0.62	0.68	0.15	0.15
20.13	499	0.06	0.00	0.57	0.63	0.67	0.15	0.14
20.25	502	0.03	0.00	0.56	0.62	0.68	0.14	0.12
20.38	505	0.03	0.00	0.46	0.62	0.65	0.12	0.12
20.50	508	0.06	0.00	0.57	0.63	0.68	0.14	0.12
20.63	511	0.03	0.00	0.52	0.60	0.59	0.09	0.09
20.75	514	0.02	0.00	0.48	0.56	0.61	0.06	0.04
20.88	517	0.00	0.00	0.40	0.51	0.49	0.00	0.00
21.00	520	0.00	0.00	0.42	0.50	0.53	0.00	0.00
21.13	523	0.00	0.00	0.40	0.51	0.55	0.00	0.00
21.25	526	0.00	0.00	0.40	0.53	0.55	0.00	0.00
21.38	529	0.00	0.00	0.39	0.51	0.53	0.00	0.00
21.50	532	0.00	0.00	0.42	0.54	0.58	0.00	0.00
21.63	535	0.00	0.00	0.43	0.57	0.56	0.00	0.00
21.75	538	0.00	0.00	0.40	0.56	0.61	0.00	0.00

Table D.2 continued

27.75	682	0.02	0.00	0.02	0.47	0.50	0.11	0.00
27.88	685	0.00	0.00	0.00	0.42	0.43	0.06	0.00
28.00	688	0.00	0.00	0.01	0.45	0.37	0.14	0.00
28.13	691	0.06	0.06	0.05	0.56	0.56	0.20	0.00
28.25	694	0.03	0.00	0.09	0.50	0.52	0.15	0.00
28.38	697	0.05	0.00	0.02	0.48	0.44	0.09	0.00
28.50	700	0.00	0.00	0.00	0.42	0.44	0.11	0.00
28.63	703	0.00	0.00	0.00	0.45	0.48	0.12	0.00
28.75	706	0.03	0.00	0.00	0.44	0.44	0.12	0.00
28.88	709	0.00	0.00	0.00	0.39	0.34	0.08	0.00
29.00	712	0.00	0.00	0.00	0.42	0.40	0.09	0.00
29.13	715	0.00	0.02	0.00	0.38	0.37	0.09	0.00
29.25	718	0.00	0.06	0.00	0.35	0.34	0.06	0.00
29.38	721	0.00	0.00	0.00	0.32	0.30	0.05	0.00
29.50	724	0.00	0.00	0.00	0.29	0.25	0.01	0.00
29.63	727	0.00	0.00	0.00	0.27	0.22	0.03	0.00
29.75	730	0.00	0.00	0.00	0.36	0.32	0.12	0.00
29.88	733	0.00	0.00	0.00	0.24	0.13	0.01	0.00
30.00	736	0.00	0.00	0.00	0.33	0.27	0.06	0.00
30.13	739	0.00	0.00	0.00	0.36	0.30	0.15	0.00
30.25	742	0.00	0.00	0.00	0.36	0.27	0.15	0.00
30.38	745	0.00	0.00	0.00	0.30	0.16	0.08	0.00
30.50	748	0.01	0.00	0.00	0.20	0.19	0.15	0.00
30.63	751	0.06	0.00	0.00	0.35	0.16	0.12	0.00
30.75	754	0.06	0.00	0.00	0.26	0.15	0.12	0.00
30.88	757	0.00	0.00	0.00	0.14	0.01	0.00	0.00
31.00	760	0.05	0.00	0.00	0.23	0.15	0.15	0.00
31.13	763	0.10	0.00	0.00	0.27	0.16	0.18	0.00
31.25	766	0.09	0.00	0.00	0.20	0.12	0.15	0.00
31.38	769	0.08	0.00	0.00	0.15	0.07	0.11	0.00
31.50	772	0.03	0.00	0.00	0.09	0.02	0.09	0.00
31.63	775	0.04	0.00	0.00	0.12	0.01	0.12	0.05
31.75	778	0.08	0.00	0.00	0.06	0.09	0.06	0.04
31.88	781	0.00	0.00	0.00	0.02	0.00	0.00	0.00
32.00	784	0.00	0.00	0.00	0.03	0.00	0.04	0.00
32.13	787	0.07	0.00	0.00	0.06	0.00	0.09	0.08
32.25	790	0.09	0.00	0.00	0.03	0.00	0.09	0.07
32.38	793	0.03	0.00	0.00	0.00	0.00	0.03	0.02
32.50	796	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32.63	799	0.06	0.00	0.00	0.00	0.00	0.06	0.04
32.75	802	0.06	0.00	0.00	0.00	0.00	0.02	0.05
32.88	805	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33.00	808	0.01	0.00	0.00	0.00	0.00	0.00	0.00
33.13	811	0.03	0.00	0.00	0.00	0.00	0.00	0.00
33.25	814	0.06	0.00	0.00	0.00	0.00	0.00	0.00
33.38	817	0.08	0.00	0.00	0.00	0.00	0.00	0.00
33.50	820	0.03	0.00	0.00	0.00	0.00	0.00	0.00

Table D.2 continued

33.63	823	0.06	0.00	0.00	0.00	0.00	0.00	0.00
33.75	826	0.03	0.00	0.00	0.00	0.00	0.00	0.00
33.88	829	0.04	0.00	0.00	0.00	0.00	0.00	0.00

Table D.3 Respirometer Raw Data: Case B-1 Cumulative Gas

		Cumulative Gas (mL)								
Time (days)	Time (hrs)	WSN	WS ½ N	S	WS (rep A)	WS (rep B)	WN	DI	½ (WSN)	Date
	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5/25/07
	4	7.77	8.22	6.29	8.24	8.57	6.51	4.71	6.28	5/25/07
	8	8.62	9.97	6.56	9.65	9.41	6.96	4.85	6.32	5/25/07
0.00	12	0.63	1.21	0.00	1.09	0.62	0.00	0.00	0.00	5/25/07
0.17	16	1.30	2.55	0.04	2.40	1.73	0.00	0.00	0.00	5/26/07
0.33	20	1.98	3.89	0.49	3.71	2.71	0.00	0.00	0.00	5/26/07
0.50	24	2.87	5.41	1.11	5.12	3.95	0.00	0.00	0.00	5/26/07
0.67	28	4.09	7.15	2.05	6.75	5.42	0.00	0.09	0.14	5/26/07
0.83	32	5.30	8.98	3.07	8.42	6.93	0.00	0.36	0.78	5/26/07
1.00	36	6.47	10.64	4.01	9.92	8.26	0.00	0.49	1.14	5/26/07
1.17	40	7.72	12.42	5.08	11.46	9.68	0.00	0.67	1.64	5/27/07
1.33	44	8.94	14.08	6.02	12.77	10.75	0.00	0.72	1.92	5/27/07
1.50	48	10.01	15.64	6.86	14.04	11.86	0.00	0.72	2.10	5/27/07
1.67	52	11.23	17.39	7.89	15.49	13.23	0.00	0.72	2.55	5/27/07
1.83	56	12.53	19.13	8.92	16.90	14.48	0.00	0.76	2.92	5/27/07
2.00	60	13.56	20.60	9.67	17.98	15.50	0.00	0.76	3.05	5/27/07
2.17	64	14.77	22.26	10.61	19.25	16.65	0.00	0.76	3.28	5/28/07
2.33	68	16.03	23.91	11.50	20.47	17.59	0.00	0.76	3.42	5/28/07
2.50	72	17.33	25.66	12.57	21.79	18.78	0.00	0.76	3.60	5/28/07
2.67	76	19.08	27.76	13.96	23.42	20.43	0.00	0.76	4.24	5/28/07
2.83	80	20.83	29.77	15.38	25.00	21.98	0.00	0.76	4.78	5/28/07
3.00	84	22.32	31.56	16.59	26.41	23.27	0.00	0.76	5.10	5/28/07
3.17	88	23.98	33.52	17.88	27.86	24.64	0.00	0.76	5.46	5/29/07
3.33	92	25.64	35.45	19.17	29.31	25.89	0.00	0.76	5.78	5/29/07
3.50	96	27.61	37.46	20.56	30.85	27.49	0.00	0.76	6.28	5/29/07
3.67	100	30.35	39.83	22.39	32.66	29.48	0.00	0.76	7.24	5/29/07
3.83	104	33.00	42.11	24.12	34.43	31.39	0.00	0.85	8.01	5/29/07

Table D.3 continued

4.00	108	35.29	44.03	25.55	35.83	32.86	0.00	0.94	8.47	5/29/07
4.17	112	37.63	45.99	27.07	37.33	34.46	0.00	0.94	9.01	5/30/07
4.33	116	39.78	48.05	28.72	38.91	36.01	0.00	1.03	9.56	5/30/07
4.50	120	41.76	50.24	30.46	39.68	37.88	0.00	1.26	10.33	5/30/07
4.67	124	43.96	52.70	32.42	42.08	39.87	0.00	1.62	11.29	5/30/07
4.83	128	46.16	55.11	34.43	44.08	41.92	0.00	1.93	12.20	5/30/07
5.00	132	47.95	57.26	36.12	45.39	43.56	0.00	2.02	12.74	5/30/07
5.17	136	49.97	59.58	38.00	46.39	45.38	0.00	2.02	13.47	5/31/07
5.33	140	51.99	62.00	39.91	48.56	47.11	0.00	2.02	14.16	5/31/07
5.50	144	54.24	64.59	41.92	50.28	49.24	0.00	2.15	15.16	5/31/07
5.67	148	56.57	67.41	44.02	51.91	51.46	0.00	2.42	16.20	5/31/07
5.83	152	59.04	70.36	46.25	54.40	53.77	0.00	2.83	17.34	5/31/07
6.00	156	61.15	72.95	48.16	56.35	55.77	0.00	2.92	18.11	5/31/07
6.17	160	63.44	75.68	50.22	58.48	57.90	0.00	2.92	19.07	6/1/07
6.33	164	65.87	78.63	52.45	60.75	60.16	0.00	3.05	20.12	6/1/07
6.50	168	68.20	81.49	54.59	62.97	62.38	0.00	3.10	21.07	6/1/07
6.67	172	70.49	84.75	57.04	65.59	64.65	0.00	3.23	22.12	6/1/07
6.83	176	73.23	88.10	59.58	68.31	67.45	0.00	3.59	23.53	6/1/07
7.00	180	75.70	91.14	61.95	70.76	69.93	0.00	3.73	24.67	6/1/07
7.17	184	78.26	94.23	64.35	73.29	72.55	0.00	4.00	25.94	6/2/07
7.33	188	80.78	97.22	66.81	75.83	75.17	0.00	4.13	27.21	6/2/07
7.50	192	83.47	100.30	69.35	78.59	77.97	0.00	4.44	28.62	6/2/07
7.67	196	86.25	103.39	72.03	81.45	80.90	0.00	4.80	30.22	6/2/07
7.83	200	88.86	106.29	74.48	84.21	83.70	0.00	5.21	31.63	6/2/07
8.00	204	91.55	109.29	77.07	87.20	86.72	0.00	5.34	33.22	6/2/07
8.17	208	94.34	112.37	79.61	90.33	89.91	0.18	5.84	34.99	6/3/07
8.33	212	96.89	115.28	82.06	93.32	92.89	0.59	6.15	36.68	6/3/07
8.50	216	99.27	118.01	84.38	96.31	95.86	0.82	6.46	38.27	6/3/07
8.67	220	101.65	120.78	86.79	99.39	99.01	1.23	6.87	40.04	6/3/07
8.83	224	103.76	123.46	89.20	102.42	102.12	1.55	7.18	41.77	6/3/07
9.00	228	105.74	125.92	91.47	105.41	105.28	1.91	7.59	43.50	6/3/07

Table D.3 continued

9.17	232	107.67	128.47	93.83	108.45	108.52	2.37	8.04	45.41	6/4/07
9.33	236	109.24	130.66	96.11	111.21	111.45	2.59	8.26	47.05	6/4/07
9.50	240	110.54	132.67	98.29	113.93	114.38	2.59	8.49	48.69	6/4/07
9.67	244	112.03	134.72	100.61	116.74	117.53	3.00	8.93	50.55	6/4/07
9.83	248	113.46	136.42	102.67	119.23	120.55	3.14	9.11	52.10	6/4/07
10.00	252	114.23	137.50	104.40	121.27	123.08	3.14	9.11	53.38	6/4/07
10.17	256	114.90	138.52	106.14	123.26	125.65	3.14	9.11	54.65	6/5/07
10.33	260	115.21	139.19	107.66	124.98	127.74	3.14	9.11	55.65	6/5/07
10.50	264	115.39	139.78	109.18	126.70	129.83	3.14	9.11	56.79	6/5/07
10.67	268	115.39	140.36	110.69	128.51	131.96	3.14	9.11	58.02	6/5/07
10.83	272	115.39	140.85	112.12	130.19	134.00	3.14	9.11	59.29	6/5/07
11.00	276	115.39	140.98	113.37	131.64	135.56	3.14	9.11	60.34	6/5/07
11.17	280	115.39	141.16	114.62	133.14	137.02	3.14	9.11	61.43	6/6/07
11.33	284	115.39	141.25	115.73	134.27	138.31	3.14	9.11	62.38	6/6/07
11.50	288	115.39	141.34	116.85	135.13	139.73	3.14	9.11	63.57	6/6/07
11.67	292	115.39	141.52	117.92	136.67	141.24	3.14	9.11	64.89	6/6/07
11.83	296	115.39	141.79	118.94	137.53	142.48	3.14	9.11	66.21	6/6/07
12.00	300	115.39	141.92	119.70	138.80	143.24	3.14	9.11	67.16	6/6/07
12.17	304	115.39	142.14	120.59	139.75	144.26	3.14	9.11	68.57	6/7/07
12.33	308	115.39	142.23	121.13	140.34	144.88	3.14	9.11	69.66	6/7/07
12.50	312	115.39	142.55	121.75	141.02	145.68	3.14	9.11	70.98	6/7/07
12.67	316	115.39	142.55	122.02	142.06	146.03	3.14	9.11	71.89	6/7/07
12.83	320	115.44	142.90	122.69	142.92	146.74	3.14	9.61	73.30	6/7/07
13.00	324	115.44	142.90	122.69	143.01	146.74	3.14	9.74	74.03	6/7/07
13.17	328	115.44	142.90	122.74	143.19	146.79	3.14	10.01	74.76	6/8/07
13.33	332	115.44	142.90	122.74	143.24	146.79	3.14	10.06	75.03	6/8/07
13.50	336	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/8/07
13.67	340	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/8/07
13.83	344	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/8/07

Table D.3 continued

14.00	348	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/8/07
14.17	352	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/9/07
14.33	356	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/9/07
14.50	360	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/9/07
14.67	364	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/9/07
14.83	368	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/9/07
15.00	372	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/9/07
15.17	376	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/10/07
15.33	380	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/10/07
15.50	384	115.44	142.90	122.74	143.24	146.79	3.14	10.19	75.40	6/10/07
15.67	388	115.44	142.90	122.74	143.46	146.79	3.14	10.19	75.40	6/10/07
15.83	392	115.44	142.90	122.74	143.46	146.79	3.14	10.19	75.40	6/10/07
16.00	396	115.44	142.90	122.74	143.65	146.79	3.14	10.19	75.40	6/10/07
16.17	400	115.44	142.90	122.74	143.65	146.79	3.14	10.19	75.40	6/11/07
16.33	404	115.44	142.90	122.74	143.65	146.79	3.14	10.19	75.40	6/11/07
16.50	407	115.44	143.08	122.74	143.65	146.79	3.14	10.19	75.40	6/11/07

Table D.4 Respirometer Calculated Data: Case B-1 Gas Production Rate

		Gas Production Rate (mL/hr)							
Time (days)	Time (hrs)	WSN	WS ½ N	S	WS (rep A)	WS (rep B)	WN	DI	½ (WSN)
	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	1.94	2.06	1.57	2.06	2.14	1.63	1.18	1.57
	8	0.21	0.44	0.07	0.35	0.21	0.11	0.03	0.01
0.00	12	0.16	0.30	0.00	0.27	0.16	0.00	0.00	0.00
0.17	16	0.17	0.34	0.01	0.33	0.28	0.00	0.00	0.00
0.33	20	0.17	0.34	0.11	0.33	0.25	0.00	0.00	0.00
0.50	24	0.22	0.38	0.16	0.35	0.31	0.00	0.00	0.00
0.67	28	0.31	0.44	0.24	0.41	0.37	0.00	0.02	0.03
0.83	32	0.30	0.46	0.26	0.42	0.38	0.00	0.07	0.16
1.00	36	0.29	0.42	0.24	0.38	0.33	0.00	0.03	0.09
1.17	40	0.31	0.45	0.27	0.39	0.36	0.00	0.04	0.13
1.33	44	0.31	0.42	0.24	0.33	0.27	0.00	0.01	0.07
1.50	48	0.27	0.39	0.21	0.32	0.28	0.00	0.00	0.04
1.67	52	0.31	0.44	0.26	0.36	0.34	0.00	0.00	0.11
1.83	56	0.32	0.44	0.26	0.35	0.31	0.00	0.01	0.09
2.00	60	0.26	0.37	0.19	0.27	0.26	0.00	0.00	0.03
2.17	64	0.30	0.41	0.24	0.32	0.29	0.00	0.00	0.06
2.33	68	0.32	0.41	0.22	0.31	0.24	0.00	0.00	0.04
2.50	72	0.32	0.44	0.27	0.33	0.30	0.00	0.00	0.04
2.67	76	0.44	0.52	0.35	0.41	0.41	0.00	0.00	0.16
2.83	80	0.44	0.50	0.36	0.40	0.39	0.00	0.00	0.14
3.00	84	0.37	0.45	0.30	0.35	0.32	0.00	0.00	0.08
3.17	88	0.42	0.49	0.32	0.36	0.34	0.00	0.00	0.09
3.33	92	0.41	0.48	0.32	0.36	0.31	0.00	0.00	0.08
3.50	96	0.49	0.50	0.35	0.39	0.40	0.00	0.00	0.13
3.67	100	0.69	0.59	0.46	0.45	0.50	0.00	0.00	0.24
3.83	104	0.66	0.57	0.43	0.44	0.48	0.00	0.02	0.19
4.00	108	0.57	0.48	0.36	0.35	0.37	0.00	0.02	0.12
4.17	112	0.59	0.49	0.38	0.38	0.40	0.00	0.00	0.14
4.33	116	0.54	0.52	0.41	0.40	0.39	0.00	0.02	0.14
4.50	120	0.50	0.55	0.44	0.19	0.47	0.00	0.06	0.19
4.67	124	0.55	0.62	0.49	0.60	0.50	0.00	0.09	0.24
4.83	128	0.55	0.60	0.50	0.50	0.51	0.00	0.08	0.23
5.00	132	0.45	0.54	0.42	0.33	0.41	0.00	0.02	0.14
5.17	136	0.51	0.58	0.47	0.25	0.45	0.00	0.00	0.18
5.33	140	0.50	0.61	0.48	0.54	0.43	0.00	0.00	0.17
5.50	144	0.56	0.65	0.50	0.43	0.53	0.00	0.03	0.25
5.67	148	0.58	0.70	0.53	0.41	0.56	0.00	0.07	0.26
5.83	152	0.62	0.74	0.56	0.62	0.58	0.00	0.10	0.29
6.00	156	0.53	0.65	0.48	0.49	0.50	0.00	0.02	0.19
6.17	160	0.57	0.68	0.52	0.53	0.53	0.00	0.00	0.24
6.33	164	0.61	0.74	0.56	0.57	0.56	0.00	0.03	0.26
6.50	168	0.58	0.72	0.54	0.56	0.56	0.00	0.01	0.24

Table D.4 continued

6.67	172	0.57	0.82	0.61	0.65	0.57	0.00	0.03	0.26
6.83	176	0.68	0.84	0.64	0.68	0.70	0.00	0.09	0.35
7.00	180	0.62	0.76	0.59	0.61	0.62	0.00	0.04	0.28
7.17	184	0.64	0.78	0.60	0.64	0.66	0.00	0.07	0.32
7.33	188	0.63	0.75	0.62	0.64	0.66	0.00	0.03	0.32
7.50	192	0.67	0.77	0.63	0.69	0.70	0.00	0.08	0.35
7.67	196	0.70	0.77	0.67	0.72	0.73	0.00	0.09	0.40
7.83	200	0.65	0.73	0.61	0.69	0.70	0.00	0.10	0.35
8.00	204	0.67	0.75	0.65	0.75	0.75	0.00	0.03	0.40
8.17	208	0.70	0.77	0.64	0.78	0.80	0.04	0.13	0.44
8.33	212	0.64	0.73	0.61	0.75	0.75	0.10	0.08	0.42
8.50	216	0.59	0.68	0.58	0.75	0.74	0.06	0.08	0.40
8.67	220	0.59	0.69	0.60	0.77	0.79	0.10	0.10	0.44
8.83	224	0.53	0.67	0.60	0.76	0.78	0.08	0.08	0.43
9.00	228	0.50	0.61	0.57	0.75	0.79	0.09	0.10	0.43
9.17	232	0.48	0.64	0.59	0.76	0.81	0.12	0.11	0.48
9.33	236	0.39	0.55	0.57	0.69	0.73	0.06	0.05	0.41
9.50	240	0.32	0.50	0.54	0.68	0.73	0.00	0.06	0.41
9.67	244	0.37	0.51	0.58	0.70	0.79	0.10	0.11	0.47
9.83	248	0.36	0.42	0.52	0.62	0.76	0.03	0.05	0.39
10.00	252	0.19	0.27	0.43	0.51	0.63	0.00	0.00	0.32
10.17	256	0.17	0.26	0.44	0.50	0.64	0.00	0.00	0.32
10.33	260	0.08	0.17	0.38	0.43	0.52	0.00	0.00	0.25
10.50	264	0.05	0.15	0.38	0.43	0.52	0.00	0.00	0.29
10.67	268	0.00	0.15	0.38	0.45	0.53	0.00	0.00	0.31
10.83	272	0.00	0.12	0.36	0.42	0.51	0.00	0.00	0.32
11.00	276	0.00	0.03	0.31	0.36	0.39	0.00	0.00	0.26
11.17	280	0.00	0.05	0.31	0.38	0.37	0.00	0.00	0.27
11.33	284	0.00	0.02	0.28	0.28	0.32	0.00	0.00	0.24
11.50	288	0.00	0.02	0.28	0.22	0.35	0.00	0.00	0.30
11.67	292	0.00	0.05	0.27	0.38	0.38	0.00	0.00	0.33
11.83	296	0.00	0.07	0.25	0.22	0.31	0.00	0.00	0.33
12.00	300	0.00	0.03	0.19	0.32	0.19	0.00	0.00	0.24
12.17	304	0.00	0.06	0.22	0.24	0.25	0.00	0.00	0.35
12.33	308	0.00	0.02	0.13	0.15	0.16	0.00	0.00	0.27
12.50	312	0.00	0.08	0.16	0.17	0.20	0.00	0.00	0.33
12.67	316	0.00	0.00	0.07	0.26	0.09	0.00	0.00	0.23
12.83	320	0.01	0.09	0.17	0.21	0.18	0.00	0.13	0.35
13.00	324	0.00	0.00	0.00	0.02	0.00	0.00	0.03	0.18
13.17	328	0.00	0.00	0.01	0.05	0.01	0.00	0.07	0.18
13.33	332	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.07
13.50	336	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.09
13.67	340	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.83	344	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.00	348	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.17	352	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.33	356	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D.4 continued

14.50	360	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.67	364	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.83	368	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.00	372	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.17	376	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.33	380	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.50	384	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.67	388	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
15.83	392	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.00	396	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
16.17	400	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.33	404	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.50	407	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00

Table D.5 Respirometer Raw Data: Case B-2 Cumulative Gas

		Cumulative Gas (mL)								
Time (days)	Time (hrs)	WSN (rep A)	WSN (rep B)	WS ½ N	WS	S	SN	½ (WSN)	DI	Date
	0	0	0	0	0	0	0	0	0	6/22/07
	4	5.75	5.1	5.35	5.03	4.8	5.1	4.22	4.6	6/22/07
0.00	8	0.04	0.04	0.14	0.18	0.08	0.04	0.00	0.18	6/22/07
0.17	12	0.09	0.04	0.18	0.27	0.08	0.04	0.00	0.36	6/23/07
0.33	16	0.09	0.04	0.18	0.27	0.08	0.04	0.00	0.36	6/23/07
0.50	20	0.09	0.04	0.18	0.27	0.08	0.04	0.00	0.36	6/23/07
0.67	24	0.09	0.04	0.36	0.68	0.08	0.04	0.00	0.40	6/23/07
0.83	28	0.49	0.17	0.80	1.09	0.31	0.04	0.00	0.68	6/23/07
1.00	32	0.63	0.31	0.98	1.22	0.35	0.04	0.00	0.68	6/23/07
1.17	36	0.76	0.35	1.07	1.31	0.35	0.04	0.00	0.68	6/24/07
1.33	40	0.90	0.49	1.16	1.40	0.35	0.04	0.00	0.68	6/24/07
1.50	44	1.07	0.67	1.21	1.58	0.35	0.04	0.00	0.68	6/24/07
1.67	48	1.34	0.93	1.21	1.86	0.39	0.04	0.00	0.68	6/24/07
1.83	52	1.66	1.25	1.21	2.17	0.66	0.04	0.00	0.77	6/24/07
2.00	56	1.70	1.25	1.21	2.22	0.71	0.04	0.00	0.77	6/24/07
2.17	60	1.70	1.25	1.21	2.22	0.71	0.04	0.00	0.77	6/25/07
2.33	64	1.70	1.25	1.21	2.22	0.71	0.04	0.00	0.77	6/25/07
2.50	68	1.70	1.25	1.21	2.22	0.71	0.04	0.00	0.77	6/25/07
2.67	72	1.70	1.25	1.21	2.31	0.71	0.04	0.00	0.77	6/25/07
2.83	76	1.88	1.43	1.21	2.54	0.79	0.31	0.00	0.77	6/25/07
3.00	80	1.97	1.52	1.21	2.63	0.88	0.45	0.00	0.77	6/25/07
3.17	84	1.97	1.52	1.21	2.63	0.88	0.45	0.00	0.77	6/26/07
3.33	88	1.97	1.52	1.21	2.63	0.88	0.45	0.00	0.77	6/26/07
3.50	92	1.97	1.52	1.21	2.63	0.88	0.45	0.00	0.77	6/26/07
3.67	96	2.11	1.65	1.21	2.90	0.97	0.72	0.00	0.77	6/26/07
3.83	100	2.65	2.05	1.21	3.35	1.46	1.18	0.00	0.81	6/26/07
4.00	104	2.78	2.19	1.21	3.44	1.59	1.32	0.00	0.91	6/26/07

Table D.5 continued

4.17	108	2.83	2.23	1.21	3.53	1.59	1.32	0.00	0.91	6/27/07
4.33	112	3.05	2.41	1.21	3.76	1.73	1.63	0.00	0.91	6/27/07
4.50	116	3.23	2.59	1.21	3.94	1.82	1.82	0.00	0.95	6/27/07
4.67	120	3.50	2.86	1.21	4.12	1.95	1.82	0.09	1.04	6/27/07
4.83	124	3.90	3.21	1.21	4.53	2.30	2.32	0.40	1.31	6/27/07
5.00	128	3.95	3.26	1.21	4.57	2.35	2.41	0.40	1.31	6/27/07
5.17	132	4.04	3.26	1.21	4.57	2.35	2.45	0.40	1.31	6/28/07
5.33	136	4.04	3.26	1.21	4.57	2.35	2.59	0.40	1.31	6/28/07
5.50	140	4.04	3.26	1.21	4.57	2.35	2.59	0.40	1.31	6/28/07
5.67	144	4.22	3.39	1.21	4.66	2.35	2.82	0.40	1.31	6/28/07
5.83	148	4.53	3.66	1.21	4.89	2.39	3.09	0.40	1.31	6/28/07
6.00	152	4.58	3.71	1.21	4.94	2.39	3.18	0.40	1.31	6/28/07
6.17	156	4.71	3.80	1.21	5.03	2.39	3.32	0.40	1.31	6/29/07
6.33	160	4.98	4.02	1.21	5.21	2.39	3.59	0.40	1.31	6/29/07
6.50	164	5.12	4.11	1.21	5.30	2.39	3.64	0.40	1.31	6/29/07
6.67	168	5.65	4.60	1.21	5.43	2.66	4.00	0.40	1.31	6/29/07
6.83	172	6.28	5.18	1.21	6.16	3.15	4.64	0.40	1.31	6/29/07
7.00	176	6.60	5.45	1.21	6.39	3.24	4.86	0.40	1.31	6/29/07
7.17	180	6.87	5.67	1.21	6.57	3.28	5.09	0.58	1.31	6/30/07
7.33	184	7.23	6.03	1.21	6.88	3.59	5.59	0.81	1.31	6/30/07
7.50	188	7.63	6.34	1.21	7.20	3.72	5.91	0.85	1.31	6/30/07
7.67	192	8.35	7.01	1.21	7.84	4.17	6.55	1.21	1.31	6/30/07
7.83	196	9.02	7.64	1.21	8.38	4.70	7.23	1.53	1.31	6/30/07
8.00	200	9.47	8.04	1.21	8.79	4.83	7.55	1.57	1.31	6/30/07
8.17	204	9.70	8.22	1.21	8.97	4.83	7.78	1.57	1.31	7/1/07
8.33	208	10.10	8.58	1.21	9.33	5.15	8.32	1.57	1.31	7/1/07
8.50	212	10.55	8.98	1.21	9.74	5.32	8.73	1.57	1.31	7/1/07
8.67	216	11.31	9.65	1.21	10.42	5.81	9.37	1.75	1.31	7/1/07
8.83	220	12.12	10.37	1.21	11.19	6.34	9.64	1.89	1.31	7/1/07
9.00	224	12.84	10.95	1.21	11.78	6.70	10.55	2.20	1.31	7/1/07
9.17	228	13.47	11.53	1.21	12.41	7.01	11.10	2.34	1.31	7/2/07

Table D.5 continued

9.33	232	14.19	12.15	1.21	13.04	7.50	11.92	2.56	1.31	7/2/07
9.50	236	15.17	13.09	1.21	14.00	8.12	12.74	2.96	1.31	7/2/07
9.67	240	16.34	14.12	1.25	15.13	8.88	13.74	3.46	1.31	7/2/07
9.83	244	17.69	15.33	1.25	16.35	9.81	14.97	4.13	1.31	7/2/07
10.00	248	18.86	16.36	1.25	17.39	10.47	15.92	4.49	1.31	7/2/07
10.17	252	20.07	17.47	1.25	18.53	11.23	17.01	4.98	1.31	7/3/07
10.33	256	21.37	18.59	1.25	19.70	12.03	18.24	5.52	1.31	7/3/07
10.50	260	22.90	19.98	1.25	21.06	12.96	19.56	6.15	1.31	7/3/07
10.67	264	24.65	21.59	1.25	22.69	14.07	21.06	6.96	1.31	7/3/07
10.83	268	26.53	23.24	1.25	24.37	15.36	22.75	7.86	1.36	7/3/07
11.00	272	28.37	24.76	1.25	26.00	16.42	24.25	8.62	1.59	7/3/07
11.17	276	30.30	26.46	1.25	27.72	17.53	25.84	9.38	1.77	7/4/07
11.33	280	32.33	28.29	1.25	29.49	18.87	27.71	10.33	2.04	7/4/07
11.50	284	34.35	30.17	1.25	31.26	20.06	29.34	11.09	2.18	7/4/07
11.67	288	36.41	32.00	1.25	32.98	21.04	30.80	11.72	2.18	7/4/07
11.83	292	38.79	34.15	1.25	35.02	22.51	32.85	12.80	2.41	7/4/07
12.00	296	41.04	36.20	1.25	36.69	23.66	34.62	13.52	2.45	7/4/07
12.17	300	43.51	38.44	1.25	38.64	24.99	36.53	14.41	2.45	7/5/07
12.33	304	45.93	40.67	1.25	40.54	26.37	38.58	15.31	2.50	7/5/07
12.50	308	48.58	43.04	1.25	42.53	27.75	40.67	16.30	2.50	7/5/07
12.67	312	51.45	45.63	1.25	44.62	29.25	42.86	17.38	2.63	7/5/07
12.83	316	54.51	48.45	1.25	46.84	30.99	45.31	18.54	2.86	7/5/07
13.00	320	57.51	50.73	1.25	48.70	32.32	47.50	19.40	2.86	7/5/07
13.17	324	60.52	53.77	1.25	50.60	33.92	49.77	20.39	2.86	7/6/07
13.33	328	63.58	56.68	1.25	52.55	35.47	52.05	21.46	2.86	7/6/07
13.50	332	66.76	59.63	1.25	54.49	37.07	54.37	22.59	2.86	7/6/07
13.67	336	70.27	62.93	1.25	56.71	38.98	57.01	23.98	2.86	7/6/07
13.83	340	73.90	66.24	1.25	58.98	40.98	59.74	25.46	2.95	7/6/07
14.00	344	77.31	69.46	1.25	60.97	42.66	62.19	26.72	3.18	7/6/07
14.17	348	80.64	72.59	1.25	62.92	44.35	64.51	27.88	3.18	7/7/07
14.33	352	83.96	75.76	1.25	64.91	46.13	67.06	29.23	3.45	7/7/07

Table D.5 continued

14.50	356	87.42	78.98	1.25	66.95	47.90	69.52	30.53	3.64	7/7/07
14.67	360	91.10	82.51	1.30	69.31	50.03	72.07	32.15	4.23	7/7/07
14.83	364	94.74	86.00	1.30	71.57	52.17	74.71	33.77	4.77	7/7/07
15.00	368	98.06	89.13	1.30	73.66	53.94	77.03	35.11	5.05	7/7/07
15.17	372	101.11	92.12	1.30	75.56	55.63	79.03	36.23	5.23	7/8/07
15.33	376	104.17	95.07	1.30	77.51	57.54	81.21	37.49	5.55	7/8/07
15.50	380	107.04	97.80	1.30	79.36	59.22	83.08	38.57	5.77	7/8/07
15.67	384	110.14	100.79	1.30	81.49	61.31	85.13	39.87	6.27	7/8/07
15.83	388	113.23	103.39	1.30	83.62	63.35	87.04	41.13	6.78	7/8/07
16.00	392	115.66	105.67	1.30	85.16	64.86	88.31	41.85	6.91	7/8/07
16.17	396	118.08	107.90	1.30	86.75	66.46	89.49	42.52	6.91	7/9/07
16.33	400	120.42	110.00	1.30	88.24	67.97	90.54	43.10	6.91	7/9/07
16.50	404	122.66	112.01	1.30	89.69	69.44	91.41	43.51	6.91	7/9/07
16.67	408	125.22	114.34	1.30	91.50	71.30	92.68	44.27	7.09	7/9/07
16.83	412	127.78	116.66	1.30	93.23	73.08	93.82	44.95	7.50	7/9/07
17.00	416	129.76	118.54	1.30	94.58	74.41	94.45	45.13	7.59	7/9/07
17.17	420	131.69	120.55	1.30	96.08	75.83	95.18	45.21	7.59	7/10/07
17.33	424	133.31	122.52	1.30	97.57	77.34	96.09	45.66	7.59	7/10/07
17.50	428	134.56	124.57	1.30	99.16	78.85	97.00	46.02	7.59	7/10/07
17.67	432	135.91	127.08	1.30	101.15	80.80	98.37	46.79	8.19	7/10/07
17.83	436	136.99	129.45	1.30	103.10	82.62	99.69	47.41	8.82	7/10/07
18.00	440	137.35	131.19	1.30	104.64	83.96	100.51	47.64	9.00	7/10/07
18.17	444	137.48	132.49	1.30	106.09	85.02	101.14	47.64	9.00	7/11/07
18.33	448	137.48	133.20	1.30	107.45	86.04	101.96	47.68	9.00	7/11/07
18.50	452	137.48	133.47	1.30	108.63	86.80	102.46	47.68	9.00	7/11/07
18.67	456	137.48	133.96	1.30	110.21	87.95	103.33	47.68	9.00	7/11/07
18.83	460	137.48	134.14	1.30	111.80	89.02	104.19	47.77	9.00	7/11/07
19.00	464	137.48	134.32	1.30	113.25	89.86	105.01	47.77	9.00	7/11/07
19.17	468	137.48	134.41	1.30	114.92	90.88	106.01	47.95	9.00	7/12/07
19.33	472	137.48	134.50	1.30	116.65	92.08	107.24	48.27	9.00	7/12/07
19.50	476	137.48	134.50	1.30	118.32	93.10	108.29	48.49	9.00	7/12/07

Table D.5 continued

19.67	480	137.48	134.50	1.30	120.09	94.17	109.42	48.72	9.00	7/12/07
19.83	484	137.48	134.50	1.30	121.81	95.14	110.61	48.94	9.00	7/12/07
20.00	488	137.48	134.50	1.30	123.30	95.99	111.56	49.08	9.00	7/12/07
20.17	492	137.48	134.50	1.30	124.85	96.79	112.56	49.17	9.00	7/13/07
20.33	496	137.48	134.50	1.30	126.25	97.54	113.52	49.17	9.00	7/13/07
20.50	500	137.48	134.50	1.30	127.52	98.25	114.47	49.17	9.00	7/13/07
20.67	504	137.48	134.50	1.30	128.47	99.10	115.34	49.44	9.00	7/13/07
20.83	508	137.48	134.50	1.30	129.15	99.54	116.16	49.44	9.00	7/13/07
21.00	512	137.48	134.50	1.30	129.92	100.52	117.20	49.44	9.00	7/13/07
21.17	516	137.48	134.50	1.30	130.64	101.58	118.21	49.62	9.00	7/14/07
21.33	520	137.48	134.50	1.30	131.41	102.83	119.16	49.79	9.00	7/14/07
21.50	524	137.48	134.72	1.30	132.14	104.16	119.93	50.51	9.00	7/14/07
21.67	528	137.48	134.77	1.30	132.27	105.31	120.34	50.92	9.00	7/14/07
21.83	532	137.48	134.77	1.43	133.09	106.60	120.75	51.37	9.00	7/14/07
22.00	536	137.48	134.77	1.61	133.09	107.49	120.84	51.55	9.00	7/14/07
22.17	540	137.48	134.77	1.61	133.50	108.15	120.84	51.55	9.00	7/15/07
22.33	544	137.48	134.77	1.61	133.54	109.17	120.84	51.55	9.00	7/15/07
22.50	548	137.48	134.77	1.61	133.54	110.11	120.84	51.55	9.00	7/15/07
22.67	552	137.48	134.77	1.61	133.63	111.31	120.84	52.04	9.00	7/15/07
22.83	556	137.48	134.77	1.61	133.72	112.64	120.84	52.53	9.00	7/15/07
23.00	560	137.48	134.77	1.61	133.72	113.57	120.84	52.62	9.00	7/15/07
23.17	564	137.48	134.77	1.61	133.72	114.46	120.84	52.67	9.00	7/16/07
23.33	568	137.48	134.77	1.61	133.72	115.57	120.84	52.85	9.00	7/16/07
23.50	572	137.48	134.77	1.61	133.72	116.77	120.84	53.12	9.00	7/16/07
23.67	576	137.48	134.77	1.61	133.72	118.01	120.84	53.61	9.00	7/16/07
23.83	580	137.48	134.77	1.61	133.86	119.25	120.84	53.97	9.00	7/16/07
24.00	584	137.48	134.77	1.61	133.86	120.27	120.84	54.19	9.00	7/16/07
24.17	588	137.48	134.77	1.61	133.86	121.34	120.84	54.42	9.00	7/17/07
24.33	592	137.48	134.81	1.61	133.86	122.67	120.84	54.96	9.00	7/17/07
24.50	596	137.48	134.81	1.61	133.86	123.65	120.84	55.27	9.00	7/17/07
24.67	600	137.71	135.30	1.88	134.49	125.43	121.12	56.66	9.37	7/17/07

Table D.5 continued

24.83	604	137.71	135.44	2.32	134.49	126.49	121.12	57.34	9.82	7/17/07
25.00	608	137.71	135.44	2.45	134.49	127.02	121.12	57.70	9.91	7/17/07
25.17	612	137.71	135.44	2.54	134.49	127.38	121.12	58.15	10.01	7/18/07
25.33	616	137.71	135.44	2.68	134.49	127.82	121.12	58.64	10.19	7/18/07
25.50	620	137.71	135.44	2.77	134.49	128.13	121.12	59.13	10.32	7/18/07
25.67	624	137.71	135.44	3.08	134.49	128.67	121.12	59.90	10.73	7/18/07
25.83	628	137.71	135.44	3.39	134.49	129.02	121.12	60.66	11.01	7/18/07
26.00	632	137.71	135.44	3.57	134.49	129.24	121.12	61.20	11.19	7/18/07
26.17	636	137.71	135.44	3.66	134.49	129.33	121.12	61.69	11.28	7/19/07
26.33	640	137.71	135.44	3.79	134.49	129.51	121.12	62.28	11.46	7/19/07
26.50	644	137.71	135.44	3.79	134.49	129.51	121.12	62.73	11.51	7/19/07
26.67	648	137.71	135.44	3.88	134.49	129.51	121.12	63.13	11.60	7/19/07
26.83	652	137.71	135.44	3.88	134.49	129.51	121.12	63.22	11.60	7/19/07
27.00	656	137.71	135.44	3.88	134.49	129.51	121.12	63.26	11.60	7/19/07
27.17	660	137.71	135.44	3.88	134.49	129.51	121.12	63.26	11.60	7/20/07
27.33	664	137.71	135.44	3.88	134.49	129.51	121.12	63.26	11.60	7/20/07
27.50	668	137.71	135.44	3.88	134.49	129.51	121.12	63.26	11.60	7/20/07
27.67	672	137.71	135.44	3.88	134.49	129.51	121.12	63.26	11.60	7/20/07
27.83	676	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/20/07
28.00	680	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/20/07
28.17	684	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/21/07
28.33	688	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/21/07
28.50	692	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/21/07
28.67	696	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/21/07
28.83	700	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/21/07
29.00	704	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/21/07
29.17	708	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/22/07
29.33	712	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/22/07
29.50	716	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/22/07
29.67	720	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/22/07
29.83	724	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/22/07

Table D.5 continued

30.00	728	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/22/07
30.17	732	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/23/07
30.33	736	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/23/07
30.50	740	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/23/07
30.67	743	137.71	135.44	3.88	134.49	129.51	121.12	63.31	11.60	7/23/07

Table D.6 Respirometer Calculated Data: Case B-2 Gas Production Rate

		Gas Production Rate (mL/hr)							
Time (days)	Time (hrs)	WSN (rep A)	WSN (rep B)	WS ½ N	WS	S	SN	½ (WSN)	DI
	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	1.44	1.28	1.34	1.26	1.21	1.28	1.06	1.15
0.00	8	0.01	0.01	0.04	0.04	0.02	0.01	0.00	0.05
0.17	12	0.01	0.00	0.01	0.02	0.00	0.00	0.00	0.04
0.33	16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.50	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.67	24	0.00	0.00	0.04	0.10	0.00	0.00	0.00	0.01
0.83	28	0.10	0.03	0.11	0.10	0.06	0.00	0.00	0.07
1.00	32	0.03	0.04	0.04	0.03	0.01	0.00	0.00	0.00
1.17	36	0.03	0.01	0.02	0.02	0.00	0.00	0.00	0.00
1.33	40	0.04	0.03	0.02	0.02	0.00	0.00	0.00	0.00
1.50	44	0.04	0.04	0.01	0.05	0.00	0.00	0.00	0.00
1.67	48	0.07	0.07	0.00	0.07	0.01	0.00	0.00	0.00
1.83	52	0.08	0.08	0.00	0.08	0.07	0.00	0.00	0.02
2.00	56	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00
2.17	60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.33	64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50	68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.67	72	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
2.83	76	0.04	0.05	0.00	0.06	0.02	0.07	0.00	0.00
3.00	80	0.02	0.02	0.00	0.02	0.02	0.03	0.00	0.00
3.17	84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.33	88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.50	92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.67	96	0.04	0.03	0.00	0.07	0.02	0.07	0.00	0.00
3.83	100	0.14	0.10	0.00	0.11	0.12	0.12	0.00	0.01
4.00	104	0.03	0.04	0.00	0.02	0.03	0.04	0.00	0.03
4.17	108	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00
4.33	112	0.06	0.04	0.00	0.06	0.04	0.08	0.00	0.00
4.50	116	0.04	0.05	0.00	0.05	0.02	0.05	0.00	0.01
4.67	120	0.07	0.07	0.00	0.04	0.03	0.00	0.02	0.02
4.83	124	0.10	0.09	0.00	0.10	0.09	0.13	0.08	0.07
5.00	128	0.01	0.01	0.00	0.01	0.01	0.02	0.00	0.00
5.17	132	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00
5.33	136	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
5.50	140	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.67	144	0.05	0.03	0.00	0.02	0.00	0.06	0.00	0.00
5.83	148	0.08	0.07	0.00	0.06	0.01	0.07	0.00	0.00
6.00	152	0.01	0.01	0.00	0.01	0.00	0.02	0.00	0.00
6.17	156	0.03	0.02	0.00	0.02	0.00	0.04	0.00	0.00
6.33	160	0.07	0.05	0.00	0.04	0.00	0.07	0.00	0.00
6.50	164	0.03	0.02	0.00	0.02	0.00	0.01	0.00	0.00
6.67	168	0.13	0.12	0.00	0.03	0.07	0.09	0.00	0.00

Table D.6 continued

6.83	172	0.16	0.15	0.00	0.18	0.12	0.16	0.00	0.00
7.00	176	0.08	0.07	0.00	0.06	0.02	0.06	0.00	0.00
7.17	180	0.07	0.05	0.00	0.04	0.01	0.06	0.04	0.00
7.33	184	0.09	0.09	0.00	0.08	0.08	0.13	0.06	0.00
7.50	188	0.10	0.08	0.00	0.08	0.03	0.08	0.01	0.00
7.67	192	0.18	0.17	0.00	0.16	0.11	0.16	0.09	0.00
7.83	196	0.17	0.16	0.00	0.14	0.13	0.17	0.08	0.00
8.00	200	0.11	0.10	0.00	0.10	0.03	0.08	0.01	0.00
8.17	204	0.06	0.05	0.00	0.05	0.00	0.06	0.00	0.00
8.33	208	0.10	0.09	0.00	0.09	0.08	0.14	0.00	0.00
8.50	212	0.11	0.10	0.00	0.10	0.04	0.10	0.00	0.00
8.67	216	0.19	0.17	0.00	0.17	0.12	0.16	0.04	0.00
8.83	220	0.20	0.18	0.00	0.19	0.13	0.07	0.04	0.00
9.00	224	0.18	0.15	0.00	0.15	0.09	0.23	0.08	0.00
9.17	228	0.16	0.15	0.00	0.16	0.08	0.14	0.03	0.00
9.33	232	0.18	0.16	0.00	0.16	0.12	0.21	0.06	0.00
9.50	236	0.25	0.24	0.00	0.24	0.16	0.21	0.10	0.00
9.67	240	0.29	0.26	0.01	0.28	0.19	0.25	0.13	0.00
9.83	244	0.34	0.30	0.00	0.31	0.23	0.31	0.17	0.00
10.00	248	0.29	0.26	0.00	0.26	0.17	0.24	0.09	0.00
10.17	252	0.30	0.28	0.00	0.28	0.19	0.27	0.12	0.00
10.33	256	0.33	0.28	0.00	0.29	0.20	0.31	0.14	0.00
10.50	260	0.38	0.35	0.00	0.34	0.23	0.33	0.16	0.00
10.67	264	0.44	0.40	0.00	0.41	0.28	0.38	0.20	0.00
10.83	268	0.47	0.41	0.00	0.42	0.32	0.42	0.23	0.01
11.00	272	0.46	0.38	0.00	0.41	0.27	0.38	0.19	0.06
11.17	276	0.48	0.43	0.00	0.43	0.28	0.40	0.19	0.04
11.33	280	0.51	0.46	0.00	0.44	0.34	0.47	0.24	0.07
11.50	284	0.51	0.47	0.00	0.44	0.30	0.41	0.19	0.04
11.67	288	0.51	0.46	0.00	0.43	0.25	0.37	0.16	0.00
11.83	292	0.60	0.54	0.00	0.51	0.37	0.51	0.27	0.06
12.00	296	0.56	0.51	0.00	0.42	0.29	0.44	0.18	0.01
12.17	300	0.62	0.56	0.00	0.49	0.33	0.48	0.22	0.00
12.33	304	0.61	0.56	0.00	0.48	0.35	0.51	0.23	0.01
12.50	308	0.66	0.59	0.00	0.50	0.34	0.52	0.25	0.00
12.67	312	0.72	0.65	0.00	0.52	0.38	0.55	0.27	0.03
12.83	316	0.76	0.71	0.00	0.56	0.44	0.61	0.29	0.06
13.00	320	0.75	0.57	0.00	0.47	0.33	0.55	0.22	0.00
13.17	324	0.75	0.76	0.00	0.48	0.40	0.57	0.25	0.00
13.33	328	0.77	0.73	0.00	0.49	0.39	0.57	0.27	0.00
13.50	332	0.80	0.74	0.00	0.49	0.40	0.58	0.28	0.00
13.67	336	0.88	0.82	0.00	0.56	0.48	0.66	0.35	0.00
13.83	340	0.91	0.83	0.00	0.57	0.50	0.68	0.37	0.02
14.00	344	0.85	0.81	0.00	0.50	0.42	0.61	0.32	0.06
14.17	348	0.83	0.78	0.00	0.49	0.42	0.58	0.29	0.00
14.33	352	0.83	0.79	0.00	0.50	0.45	0.64	0.34	0.07
14.50	356	0.87	0.81	0.00	0.51	0.44	0.62	0.32	0.05

Table D.6 continued

14.67	360	0.92	0.88	0.01	0.59	0.53	0.64	0.40	0.15
14.83	364	0.91	0.87	0.00	0.56	0.54	0.66	0.41	0.14
15.00	368	0.83	0.78	0.00	0.52	0.44	0.58	0.33	0.07
15.17	372	0.76	0.75	0.00	0.48	0.42	0.50	0.28	0.04
15.33	376	0.77	0.74	0.00	0.49	0.48	0.55	0.32	0.08
15.50	380	0.72	0.68	0.00	0.46	0.42	0.47	0.27	0.05
15.67	384	0.77	0.75	0.00	0.53	0.52	0.51	0.33	0.13
15.83	388	0.77	0.65	0.00	0.53	0.51	0.48	0.32	0.13
16.00	392	0.61	0.57	0.00	0.38	0.38	0.32	0.18	0.03
16.17	396	0.61	0.56	0.00	0.40	0.40	0.30	0.17	0.00
16.33	400	0.59	0.53	0.00	0.37	0.38	0.26	0.15	0.00
16.50	404	0.56	0.50	0.00	0.36	0.37	0.22	0.10	0.00
16.67	408	0.64	0.58	0.00	0.45	0.47	0.32	0.19	0.04
16.83	412	0.64	0.58	0.00	0.43	0.45	0.29	0.17	0.10
17.00	416	0.49	0.47	0.00	0.34	0.33	0.16	0.04	0.02
17.17	420	0.48	0.50	0.00	0.38	0.36	0.18	0.02	0.00
17.33	424	0.41	0.49	0.00	0.37	0.38	0.23	0.11	0.00
17.50	428	0.31	0.51	0.00	0.40	0.38	0.23	0.09	0.00
17.67	432	0.34	0.63	0.00	0.50	0.49	0.34	0.19	0.15
17.83	436	0.27	0.59	0.00	0.49	0.46	0.33	0.16	0.16
18.00	440	0.09	0.43	0.00	0.39	0.34	0.20	0.06	0.04
18.17	444	0.03	0.33	0.00	0.36	0.26	0.16	0.00	0.00
18.33	448	0.00	0.18	0.00	0.34	0.26	0.21	0.01	0.00
18.50	452	0.00	0.07	0.00	0.29	0.19	0.13	0.00	0.00
18.67	456	0.00	0.12	0.00	0.40	0.29	0.22	0.00	0.00
18.83	460	0.00	0.05	0.00	0.40	0.27	0.22	0.02	0.00
19.00	464	0.00	0.04	0.00	0.36	0.21	0.20	0.00	0.00
19.17	468	0.00	0.02	0.00	0.42	0.26	0.25	0.04	0.00
19.33	472	0.00	0.02	0.00	0.43	0.30	0.31	0.08	0.00
19.50	476	0.00	0.00	0.00	0.42	0.26	0.26	0.05	0.00
19.67	480	0.00	0.00	0.00	0.44	0.27	0.28	0.06	0.00
19.83	484	0.00	0.00	0.00	0.43	0.24	0.30	0.05	0.00
20.00	488	0.00	0.00	0.00	0.37	0.21	0.24	0.04	0.00
20.17	492	0.00	0.00	0.00	0.39	0.20	0.25	0.02	0.00
20.33	496	0.00	0.00	0.00	0.35	0.19	0.24	0.00	0.00
20.50	500	0.00	0.00	0.00	0.32	0.18	0.24	0.00	0.00
20.67	504	0.00	0.00	0.00	0.24	0.21	0.22	0.07	0.00
20.83	508	0.00	0.00	0.00	0.17	0.11	0.21	0.00	0.00
21.00	512	0.00	0.00	0.00	0.19	0.24	0.26	0.00	0.00
21.17	516	0.00	0.00	0.00	0.18	0.27	0.25	0.05	0.00
21.33	520	0.00	0.00	0.00	0.19	0.31	0.24	0.04	0.00
21.50	524	0.00	0.05	0.00	0.18	0.33	0.19	0.18	0.00
21.67	528	0.00	0.01	0.00	0.03	0.29	0.10	0.10	0.00
21.83	532	0.00	0.00	0.03	0.20	0.32	0.10	0.11	0.00
22.00	536	0.00	0.00	0.04	0.00	0.22	0.02	0.04	0.00
22.17	540	0.00	0.00	0.00	0.10	0.16	0.00	0.00	0.00
22.33	544	0.00	0.00	0.00	0.01	0.25	0.00	0.00	0.00

Table D.6 continued

22.50	548	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00
22.67	552	0.00	0.00	0.00	0.02	0.30	0.00	0.12	0.00
22.83	556	0.00	0.00	0.00	0.02	0.33	0.00	0.12	0.00
23.00	560	0.00	0.00	0.00	0.00	0.23	0.00	0.02	0.00
23.17	564	0.00	0.00	0.00	0.00	0.22	0.00	0.01	0.00
23.33	568	0.00	0.00	0.00	0.00	0.28	0.00	0.04	0.00
23.50	572	0.00	0.00	0.00	0.00	0.30	0.00	0.07	0.00
23.67	576	0.00	0.00	0.00	0.00	0.31	0.00	0.12	0.00
23.83	580	0.00	0.00	0.00	0.03	0.31	0.00	0.09	0.00
24.00	584	0.00	0.00	0.00	0.00	0.25	0.00	0.05	0.00
24.17	588	0.00	0.00	0.00	0.00	0.27	0.00	0.06	0.00
24.33	592	0.00	0.01	0.00	0.00	0.33	0.00	0.14	0.00
24.50	596	0.00	0.00	0.00	0.00	0.25	0.00	0.08	0.00
24.67	600	0.06	0.12	0.07	0.16	0.45	0.07	0.35	0.09
24.83	604	0.00	0.03	0.11	0.00	0.27	0.00	0.17	0.11
25.00	608	0.00	0.00	0.03	0.00	0.13	0.00	0.09	0.02
25.17	612	0.00	0.00	0.02	0.00	0.09	0.00	0.11	0.02
25.33	616	0.00	0.00	0.03	0.00	0.11	0.00	0.12	0.04
25.50	620	0.00	0.00	0.02	0.00	0.08	0.00	0.12	0.03
25.67	624	0.00	0.00	0.08	0.00	0.13	0.00	0.19	0.10
25.83	628	0.00	0.00	0.08	0.00	0.09	0.00	0.19	0.07
26.00	632	0.00	0.00	0.04	0.00	0.05	0.00	0.14	0.04
26.17	636	0.00	0.00	0.02	0.00	0.02	0.00	0.12	0.02
26.33	640	0.00	0.00	0.03	0.00	0.05	0.00	0.15	0.04
26.50	644	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.01
26.67	648	0.00	0.00	0.02	0.00	0.00	0.00	0.10	0.02
26.83	652	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
27.00	656	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
27.17	660	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27.33	664	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27.50	668	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27.67	672	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27.83	676	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
28.00	680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28.17	684	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28.33	688	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28.50	692	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28.67	696	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28.83	700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.00	704	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.17	708	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.33	712	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.50	716	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.67	720	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.83	724	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30.00	728	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30.17	732	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D.6 continued

30.33	736	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30.50	740	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30.67	743	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D.7 Respirometer Raw Data: Case C Cumulative Gas

		Cumulative Gas (mL)								
Days	Time (hrs)	W,S,N	W,M,S,N	W,M,S	W,S	M,S,N	M,S	S,N	M	Date
	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8/16/07
	4	19.98	19.36	17.80	15.31	9.81	8.24	8.76	9.15	8/16/07
0.00	8	0.90	0.98	0.66	0.50	0.00	0.18	0.04	0.50	8/16/07
0.17	12	4.00	2.86	1.78	0.95	0.00	0.18	0.04	0.91	8/17/07
0.33	16	21.10	6.92	6.37	2.18	0.00	0.31	0.04	1.63	8/17/07
0.50	20	30.94	12.65	24.03	7.70	0.05	0.45	0.04	2.27	8/17/07
0.67	24	30.94	14.70	28.54	29.22	0.05	0.68	0.04	3.04	8/17/07
0.83	28	30.94	15.91	28.54	41.04	0.80	0.86	0.04	3.68	8/17/07
1.00	32	30.94	17.16	28.54	41.09	1.11	0.86	0.04	4.09	8/17/07
1.17	36	30.94	18.55	28.54	41.09	1.11	0.86	0.04	4.45	8/18/07
1.33	40	30.94	20.42	28.54	41.09	1.11	0.86	0.04	5.18	8/18/07
1.50	44	30.94	22.57	28.54	41.09	1.11	0.86	0.04	5.96	8/18/07
1.67	48	30.94	25.12	28.54	41.09	1.11	0.86	0.04	6.96	8/18/07
1.83	52	30.94	27.75	28.54	41.09	1.11	0.86	0.04	8.14	8/18/07
2.00	56	30.94	30.08	28.58	41.09	1.11	1.00	0.04	9.19	8/18/07
2.17	60	30.94	32.54	28.58	41.09	1.11	1.13	0.04	10.32	8/19/07
2.33	64	30.94	35.35	28.58	41.09	1.11	1.54	0.04	11.73	8/19/07
2.50	68	31.03	37.90	28.58	41.09	1.11	1.72	0.04	12.92	8/19/07
2.67	72	31.65	40.49	28.58	41.09	1.11	1.82	0.04	14.15	8/19/07
2.83	76	32.24	42.95	28.58	41.09	2.09	2.09	0.04	15.51	8/19/07
3.00	80	32.37	45.14	28.58	41.09	2.76	2.23	0.13	16.79	8/19/07
3.17	84	33.05	47.56	28.99	41.09	3.78	2.68	0.67	18.29	8/20/07
3.33	88	33.72	50.19	29.74	41.09	5.06	3.50	1.16	20.06	8/20/07
3.50	92	34.08	52.52	30.37	41.13	6.26	4.09	1.43	21.61	8/20/07
3.67	96	34.57	54.62	31.22	41.22	7.64	4.68	1.61	23.16	8/20/07
3.83	100	34.98	56.63	32.11	41.22	9.10	5.46	2.06	24.98	8/20/07
4.00	104	35.34	58.42	33.00	41.22	10.35	6.27	2.38	26.80	8/20/07

Table D.7 continued

4.17	108	35.92	60.38	34.11	41.22	11.77	7.32	2.91	28.84	8/21/07
4.33	112	36.50	62.35	35.36	41.22	13.23	8.55	3.45	31.07	8/21/07
4.50	116	37.04	64.23	36.57	41.22	14.57	9.73	3.95	33.30	8/21/07
4.67	120	37.99	66.33	38.31	41.22	16.52	11.19	4.84	36.03	8/21/07
4.83	124	38.75	68.34	40.14	41.22	18.38	12.55	5.61	38.85	8/21/07
5.00	128	39.65	70.40	41.83	41.22	20.43	14.01	6.37	41.86	8/21/07
5.17	132	40.95	72.54	43.79	41.22	22.78	15.69	7.31	45.36	8/22/07
5.33	136	42.30	74.60	45.76	41.22	25.27	17.42	8.39	49.09	8/22/07
5.50	140	43.96	76.97	48.03	41.22	28.20	19.47	9.65	53.32	8/22/07
5.67	144	45.75	79.34	50.35	41.22	31.48	21.70	11.00	58.05	8/22/07
5.83	148	47.55	82.20	53.02	41.22	35.39	24.34	12.43	63.51	8/22/07
6.00	152	49.12	84.88	55.61	42.09	39.47	26.93	13.69	69.47	8/22/07
6.17	156	50.92	87.83	58.24	43.31	43.96	29.84	15.04	76.03	8/23/07
6.33	160	52.89	91.18	61.10	45.03	48.80	33.21	16.47	83.35	8/23/07
6.50	164	55.18	94.98	64.26	47.48	54.08	36.85	18.00	91.50	8/23/07
6.67	168	58.01	99.72	68.06	50.69	60.16	41.04	19.93	100.96	8/23/07
6.83	172	61.20	104.91	72.34	53.91	66.65	45.59	22.04	111.65	8/23/07
7.00	176	63.94	110.14	76.35	55.72	73.17	49.91	23.84	122.85	8/23/07
7.17	180	67.35	116.26	81.39	56.49	80.90	55.10	26.17	135.59	8/24/07
7.33	184	71.08	123.01	86.88	56.58	89.29	60.74	28.64	149.60	8/24/07
7.50	188	75.30	130.34	93.03	56.76	98.30	66.74	31.29	164.89	8/24/07
7.67	192	80.24	138.88	100.61	56.76	108.56	73.66	34.66	181.90	8/24/07
7.83	196	85.85	148.49	109.18	56.76	119.57	81.12	38.38	200.42	8/24/07
8.00	200	91.42	158.50	118.19	56.81	130.89	88.58	41.93	219.76	8/24/07
8.17	204	97.97	169.68	128.58	56.81	143.46	96.77	45.97	240.60	8/25/07
8.33	208	105.34	182.10	140.40	56.81	157.09	105.74	50.42	262.85	8/25/07
8.50	212	113.01	195.38	153.29	56.81	171.16	114.75	54.91	285.69	8/25/07
8.67	216	121.14	209.19	167.29	56.81	185.77	123.89	59.53	308.94	8/25/07
8.83	220	130.39	224.39	183.21	56.81	201.31	133.86	64.74	332.83	8/25/07
9.00	224	140.09	240.21	200.12	56.81	217.07	143.68	70.04	356.53	8/25/07
9.17	228	150.68	257.02	218.31	56.81	233.32	153.65	75.70	379.83	8/26/07

Table D.7 continued

9.33	232	162.18	274.72	237.89	56.81	250.06	163.75	81.71	402.44	8/26/07
9.50	236	174.44	293.09	258.32	56.81	266.98	173.76	87.95	423.83	8/26/07
9.67	240	188.13	312.40	280.17	56.81	284.65	183.91	94.91	443.85	8/26/07
9.83	244	202.81	332.74	302.21	56.81	302.68	194.01	102.19	462.28	8/26/07
10.00	248	217.99	353.08	323.61	56.81	320.48	203.74	109.37	478.06	8/26/07
10.17	252	233.48	373.46	344.08	56.81	338.37	212.80	116.83	491.85	8/27/07
10.33	256	249.29	393.62	362.91	56.81	356.62	221.44	124.41	503.59	8/27/07
10.50	260	265.05	413.25	379.63	56.81	374.83	229.32	132.00	513.78	8/27/07
10.67	264	281.12	432.74	393.95	56.85	393.48	236.91	140.04	523.47	8/27/07
10.83	268	296.92	451.20	404.96	56.85	411.81	244.24	148.21	532.85	8/27/07
11.00	272	311.61	467.83	411.52	56.85	429.13	250.38	155.84	541.26	8/27/07
11.17	276	325.57	482.53	414.15	56.85	445.65	255.98	163.39	549.27	8/28/07
11.33	280	338.32	495.54	415.22	56.85	461.81	261.44	170.93	557.32	8/28/07
11.50	284	349.86	506.40	415.98	56.85	477.21	266.58	178.16	565.11	8/28/07
11.67	288	360.41	515.88	416.78	57.35	492.80	271.95	185.21	572.93	8/28/07
11.83	292	368.94	523.30	417.72	58.35	508.16	277.77	192.53	580.98	8/28/07
12.00	296	375.01	528.89	418.57	58.94	522.63	283.51	199.35	588.45	8/28/07
12.17	300	378.78	533.94	419.68	59.34	536.62	289.83	206.22	596.00	8/29/07
12.33	304	379.94	538.85	420.89	59.71	549.90	296.79	213.27	603.42	8/29/07
12.50	308	380.53	543.95	422.36	60.07	562.24	304.12	220.63	610.97	8/29/07
12.67	312	381.29	549.27	424.32	60.48	573.83	312.31	228.72	618.89	8/29/07
12.83	316	381.92	554.95	426.55	61.34	585.06	321.09	237.25	626.71	8/29/07
13.00	320	381.92	560.26	428.47	61.52	594.87	329.51	245.60	634.27	8/29/07
13.17	324	381.92	566.25	430.88	61.75	604.42	338.20	254.58	642.05	8/30/07
13.33	328	381.92	572.87	433.69	61.97	613.74	347.21	263.78	650.05	8/30/07
13.50	332	381.92	580.47	437.16	62.20	622.89	356.31	273.26	658.52	8/30/07
13.67	336	381.96	589.23	441.36	62.52	631.99	365.63	283.00	667.53	8/30/07
13.83	340	382.32	599.06	446.13	63.24	640.69	375.05	292.92	676.72	8/30/07
14.00	344	382.59	609.75	451.17	63.69	648.38	384.20	302.71	685.27	8/30/07
14.17	348	382.82	621.15	456.65	64.10	655.83	393.34	312.63	692.91	8/31/07
14.33	352	383.13	633.44	462.68	64.51	662.89	402.58	322.56	699.97	8/31/07

Table D.7 continued

14.50	356	383.45	646.18	469.14	64.87	669.47	411.59	332.39	706.47	8/31/07
14.67	360	383.81	659.19	476.06	65.01	675.68	420.23	342.18	712.57	8/31/07
14.83	364	384.61	672.95	484.13	65.01	682.43	429.61	352.28	719.03	8/31/07
15.00	368	385.02	686.36	492.29	65.10	688.60	438.30	361.17	724.86	8/31/07
15.17	372	385.33	699.51	500.99	65.37	694.68	446.99	369.34	730.73	9/1/07
15.33	376	385.83	712.83	510.31	65.64	700.90	455.68	376.75	736.73	9/1/07
15.50	380	386.23	726.10	520.08	65.87	707.12	464.10	382.90	742.69	9/1/07
15.67	384	387.08	739.51	530.47	66.91	713.60	472.60	388.74	749.11	9/1/07
15.83	388	388.12	753.37	541.26	67.50	720.13	481.11	393.90	755.70	9/1/07
16.00	392	389.06	766.69	552.23	67.95	726.56	489.48	398.21	762.30	9/1/07
16.17	396	390.09	779.70	563.25	68.31	733.00	497.63	401.90	768.95	9/2/07
16.33	400	391.26	792.39	574.35	68.72	739.75	505.82	405.22	775.36	9/2/07
16.50	404	392.61	804.95	585.77	69.13	746.59	513.74	408.27	780.68	9/2/07
16.67	408	394.36	817.25	597.46	69.49	754.40	521.88	411.32	785.42	9/2/07
16.83	412	396.38	829.27	609.32	69.81	763.19	529.93	414.42	789.88	9/2/07
17.00	416	398.31	840.53	621.14	70.35	772.83	537.49	417.30	794.11	9/2/07
17.17	420	400.28	851.22	632.60	70.99	783.53	544.49	419.95	798.34	9/3/07
17.33	424	402.44	861.32	644.02	71.48	795.34	550.86	422.55	802.75	9/3/07
17.50	428	404.68	870.75	655.21	71.85	807.33	556.82	425.06	807.35	9/3/07
17.67	432	407.33	879.91	666.59	72.48	817.45	562.78	427.80	812.49	9/3/07
17.83	436	410.25	888.45	677.83	73.12	824.02	568.29	430.54	817.95	9/3/07
18.00	440	412.99	895.87	688.31	73.34	827.66	573.11	432.88	822.32	9/3/07
18.17	444	416.04	902.85	698.61	73.80	830.28	577.71	435.17	825.55	9/4/07
18.33	448	419.14	909.10	708.38	74.07	832.55	582.08	437.46	828.19	9/4/07
18.50	452	422.33	914.78	717.83	74.43	834.86	586.26	439.66	830.51	9/4/07
18.67	456	426.06	920.28	727.15	74.84	837.39	590.40	442.08	832.96	9/4/07
18.83	460	429.87	925.55	736.16	75.20	839.92	594.45	444.55	835.69	9/4/07
19.00	464	433.51	930.38	744.82	75.61	842.36	597.96	446.75	838.06	9/4/07
19.17	468	437.10	934.85	754.09	76.20	844.71	600.91	448.82	840.33	9/5/07
19.33	472	440.92	939.19	762.66	76.51	847.15	603.96	451.06	842.75	9/5/07
19.50	476	444.91	943.30	769.93	76.69	849.60	606.51	453.13	845.07	9/5/07

Table D.7 continued

19.67	480	449.58	947.86	777.02	77.28	852.79	609.15	455.69	847.89	9/5/07
19.83	484	454.30	952.28	783.39	77.78	856.12	611.65	458.16	850.75	9/5/07
20.00	488	459.01	956.44	788.97	78.01	859.32	613.74	460.36	853.39	9/5/07
20.17	492	463.95	960.42	793.92	78.23	862.69	615.70	462.65	856.17	9/6/07
20.33	496	469.30	964.80	798.34	78.55	866.69	617.93	465.11	859.08	9/6/07
20.50	500	474.64	969.05	801.99	78.73	870.86	619.98	467.49	861.99	9/6/07
20.67	504	480.57	973.74	805.20	79.05	875.75	622.34	470.10	865.50	9/6/07
20.83	508	487.03	978.88	808.10	79.59	881.30	624.98	473.02	869.32	9/6/07
21.00	512	493.32	983.89	810.29	79.91	886.85	627.71	475.76	872.91	9/6/07
21.17	516	500.01	989.25	812.21	80.27	893.06	630.72	478.63	876.83	9/7/07
21.33	520	507.24	995.20	814.08	80.77	900.03	634.27	481.82	881.06	9/7/07
21.50	524	514.82	1001.95	815.91	81.27	907.45	638.27	485.10	885.56	9/7/07
21.67	528	522.77	1009.41	817.74	81.81	915.53	642.64	488.51	890.25	9/7/07
21.83	532	530.76	1017.41	819.34	82.22	923.92	647.92	491.47	895.07	9/7/07
22.00	536	538.85	1025.82	820.46	82.27	932.36	653.28	494.52	899.71	9/7/07
22.17	540	547.11	1034.58	821.48	82.27	941.42	659.15	497.71	904.44	9/8/07
22.33	544	555.73	1043.16	822.69	82.27	951.41	666.16	501.26	909.77	9/8/07
22.50	548	564.80	1050.18	823.98	82.27	961.88	673.08	504.94	915.18	9/8/07
22.67	552	574.41	1055.27	825.68	82.27	973.21	679.86	508.94	921.19	9/8/07
22.83	556	584.37	1058.40	827.46	82.27	985.28	685.54	513.29	927.56	9/8/07
23.00	560	594.39	1060.32	829.15	82.27	997.76	689.73	517.87	934.02	9/8/07
23.17	564	605.03	1062.20	830.98	82.27	1010.90	692.91	523.48	940.84	9/9/07
23.33	568	615.67	1063.94	832.90	82.27	1024.27	695.10	529.23	947.94	9/9/07
23.50	572	626.18	1065.46	834.73	82.27	1037.81	696.55	535.16	955.22	9/9/07
23.67	576	637.00	1067.16	836.87	82.63	1052.06	698.15	541.62	963.09	9/9/07
23.83	580	647.73	1068.82	838.97	83.17	1066.58	699.83	548.40	971.19	9/9/07
24.00	584	658.14	1070.20	840.71	83.44	1081.05	701.29	555.09	979.06	9/9/07
24.17	588	668.20	1071.28	842.44	83.53	1095.97	702.83	562.01	987.12	9/10/07
24.33	592	678.26	1072.84	844.32	83.85	1111.60	704.88	569.51	995.63	9/10/07
24.50	596	687.64	1074.36	846.24	84.08	1127.36	706.84	577.36	1004.27	9/10/07
24.67	600	696.98	1076.24	848.47	84.35	1143.70	709.20	585.90	1013.14	9/10/07

Table D.7 continued

24.83	604	705.96	1078.29	851.01	84.62	1160.62	712.02	595.19	1022.11	9/10/07
25.00	608	713.91	1080.13	853.24	84.85	1177.27	714.80	604.62	1030.52	9/10/07
25.17	612	721.63	1082.00	855.87	85.75	1194.67	718.12	614.95	1038.81	9/11/07
25.33	616	728.46	1084.46	858.32	86.25	1211.99	721.67	625.81	1045.45	9/11/07
25.50	620	734.74	1086.70	860.78	86.61	1229.26	724.86	636.90	1049.36	9/11/07
25.67	624	740.81	1089.42	863.54	87.07	1246.84	728.72	647.99	1051.91	9/11/07
25.83	628	746.01	1092.06	866.08	87.29	1263.05	732.73	658.59	1053.46	9/11/07
26.00	632	749.38	1094.25	868.13	87.43	1275.39	736.28	668.11	1054.46	9/11/07
26.17	636	752.12	1096.75	870.54	87.57	1288.18	739.92	677.31	1055.55	9/12/07
26.33	640	754.19	1098.45	873.00	87.57	1301.06	743.87	686.02	1056.73	9/12/07
26.50	644	755.94	1100.55	875.49	87.57	1313.62	747.47	694.15	1057.78	9/12/07
26.67	648	757.91	1103.10	878.53	87.57	1325.96	751.29	702.14	1059.10	9/12/07
26.83	652	759.57	1105.38	881.69	87.57	1336.58	755.16	709.91	1060.60	9/12/07
27.00	656	761.46	1107.53	885.08	87.57	1341.86	758.94	717.36	1062.06	9/12/07
27.17	660	763.21	1110.30	888.65	87.57	1344.83	762.76	724.68	1063.56	9/13/07
27.33	664	764.92	1112.71	892.44	87.57	1346.79	766.72	732.22	1065.20	9/13/07
27.50	668	766.67	1115.48	896.46	87.57	1348.08	770.81	739.77	1066.70	9/13/07
27.67	672	768.69	1118.17	900.83	87.57	1349.41	775.32	747.72	1068.38	9/13/07
27.83	676	770.66	1120.98	904.35	87.57	1350.83	780.32	755.93	1070.16	9/13/07
28.00	680	772.37	1123.26	907.25	87.57	1351.80	785.23	763.88	1071.34	9/13/07
28.17	684	774.03	1125.23	909.79	87.57	1352.78	790.56	771.96	1072.43	9/14/07
28.33	688	775.83	1127.51	912.29	88.16	1354.07	796.56	780.31	1073.61	9/14/07
28.50	692	777.08	1129.47	914.25	88.38	1355.05	802.52	788.08	1074.25	9/14/07
28.67	696	778.39	1131.40	916.08	88.47	1355.89	808.62	795.40	1074.71	9/14/07
28.83	700	779.51	1133.59	917.73	88.52	1356.78	815.13	802.36	1075.16	9/14/07
29.00	704	780.50	1135.64	919.11	88.52	1357.58	821.86	808.96	1075.43	9/14/07
29.17	708	781.48	1137.88	920.45	88.52	1358.46	829.23	815.29	1075.80	9/15/07
29.33	712	782.43	1140.16	921.61	88.52	1359.26	837.01	821.04	1076.16	9/15/07
29.50	716	783.51	1142.62	922.64	88.52	1360.15	845.07	826.96	1076.16	9/15/07
29.67	720	784.94	1145.66	924.06	88.52	1361.31	853.94	833.16	1077.03	9/15/07
29.83	724	786.29	1149.01	925.62	88.52	1362.51	863.08	839.49	1077.94	9/15/07

Table D.7 continued

30.00	728	788.09	1152.41	927.01	88.52	1363.93	872.23	845.64	1078.66	9/15/07
30.17	732	789.70	1156.03	928.34	88.52	1365.04	881.38	851.75	1079.30	9/16/07
30.33	736	791.23	1159.83	929.68	88.52	1366.46	890.61	857.77	1079.94	9/16/07
30.50	740	792.89	1163.89	931.02	88.52	1367.61	899.99	863.56	1080.57	9/16/07
30.67	744	794.73	1168.50	932.58	88.52	1369.12	909.90	870.02	1081.48	9/16/07
30.83	748	797.02	1173.41	934.41	88.52	1370.59	920.37	876.53	1082.58	9/16/07
31.00	752	798.95	1178.56	935.84	88.52	1371.96	930.74	882.68	1083.35	9/16/07
31.17	756	801.02	1184.01	937.31	88.52	1373.34	941.39	888.88	1084.17	9/17/07
31.33	760	803.08	1189.55	938.74	88.52	1374.67	952.22	894.99	1084.85	9/17/07
31.50	764	805.24	1195.41	940.21	88.52	1376.14	963.37	901.14	1085.63	9/17/07
31.67	768	807.80	1202.02	942.04	88.52	1377.69	975.01	907.60	1086.67	9/17/07
31.83	772	810.36	1208.82	943.91	88.52	1379.07	987.12	914.16	1087.81	9/17/07
32.00	776	812.91	1215.52	945.60	88.52	1380.35	999.08	920.22	1088.72	9/17/07
32.17	780	815.43	1222.76	947.34	88.52	1381.33	1011.19	926.19	1089.63	9/18/07
32.33	784	818.08	1230.00	949.13	88.52	1382.44	1023.75	931.85	1090.68	9/18/07
32.50	788	820.55	1237.47	950.78	88.52	1383.02	1036.26	936.21	1091.54	9/18/07
32.67	792	823.56	1245.87	952.92	88.52	1384.04	1049.45	939.89	1092.86	9/18/07
32.83	796	826.21	1254.72	955.15	88.97	1384.93	1062.88	942.85	1094.18	9/18/07
33.00	800	828.81	1263.57	957.02	89.38	1385.59	1075.98	944.42	1095.13	9/18/07
33.17	804	831.19	1272.87	959.03	89.60	1386.17	1089.22	945.36	1096.14	9/19/07
33.33	808	833.30	1281.86	960.95	89.83	1386.75	1102.60	945.90	1097.23	9/19/07
33.50	812	835.63	1290.93	963.18	90.15	1387.28	1116.06	946.58	1098.55	9/19/07
33.67	816	837.79	1300.77	965.45	90.42	1388.04	1129.71	947.07	1099.87	9/19/07
33.83	820	839.85	1311.05	967.73	90.69	1388.61	1143.27	947.48	1101.19	9/19/07
34.00	824	841.52	1321.33	969.78	90.83	1388.79	1156.20	947.52	1102.05	9/19/07
34.17	828	843.49	1332.19	971.65	90.96	1389.06	1168.94	947.57	1103.05	9/20/07
34.33	832	845.65	1343.19	973.84	91.10	1389.46	1181.22	947.70	1104.14	9/20/07
34.50	836	847.80	1354.45	976.29	91.24	1389.81	1192.37	947.79	1105.24	9/20/07
34.67	840	850.72	1366.38	979.46	91.46	1390.65	1201.24	948.28	1106.78	9/20/07
34.83	844	854.18	1378.99	982.62	91.69	1391.54	1206.47	948.87	1108.47	9/20/07
35.00	848	857.77	1391.95	985.61	91.82	1392.12	1209.39	948.96	1109.88	9/20/07

Table D.7 continued

35.17	852	861.77	1405.27	988.64	91.92	1392.16	1210.89	949.36	1111.06	9/21/07
35.33	856	866.17	1418.68	991.94	92.05	1392.87	1212.16	949.77	1112.65	9/21/07
35.50	860	871.11	1432.27	995.51	92.19	1393.32	1213.21	950.12	1114.20	9/21/07
35.67	864	876.76	1446.31	999.35	92.87	1393.85	1214.53	950.62	1116.16	9/21/07
35.83	868	883.00	1460.52	1003.45	93.41	1394.65	1215.89	951.29	1118.29	9/21/07
36.00	872	889.20	1474.69	1007.33	93.59	1395.09	1216.98	951.65	1120.07	9/21/07
36.17	876	895.76	1489.53	1011.30	93.82	1395.67	1217.53	952.06	1122.03	9/21/07
36.33	880	901.82	1503.43	1014.78	93.86	1395.89	1218.62	952.14	1123.44	9/21/07
36.50	884	907.74	1517.11	1018.21	93.86	1395.89	1219.21	952.14	1124.80	9/21/07
36.67	888	913.98	1530.43	1022.32	93.86	1395.89	1220.12	952.14	1126.62	9/21/07
36.83	892	920.32	1543.80	1026.73	93.86	1396.12	1221.35	952.14	1128.80	9/21/07
37.00	896	926.51	1555.78	1031.33	93.86	1396.56	1222.53	952.14	1130.94	9/21/07
37.17	900	932.57	1565.93	1036.10	93.86	1396.56	1223.81	952.14	1133.13	9/21/07
37.33	904	938.55	1572.05	1041.05	93.86	1397.00	1225.08	952.14	1135.40	9/21/07
37.50	908	944.47	1576.03	1046.18	93.86	1397.00	1226.31	952.14	1137.63	9/21/07
37.67	912	950.76	1578.98	1052.24	93.86	1397.76	1228.09	952.14	1140.00	9/21/07
37.83	916	957.13	1581.17	1058.58	93.86	1398.42	1229.95	952.59	1141.59	9/21/07
38.00	920	963.11	1582.82	1064.86	93.86	1398.65	1231.36	952.77	1142.36	9/21/07
38.17	924	969.03	1584.12	1071.29	93.86	1399.14	1232.77	952.86	1142.91	9/21/07
38.33	928	975.05	1585.59	1078.20	93.86	1399.67	1234.46	953.22	1143.68	9/21/07
38.50	932	981.11	1586.76	1085.25	93.86	1399.93	1236.00	953.36	1144.23	9/21/07
38.67	936	987.76	1588.14	1093.14	93.86	1400.87	1237.91	953.94	1145.23	9/21/07
38.83	940	994.13	1589.26	1101.39	93.86	1401.44	1239.78	954.43	1146.19	9/21/07
39.00	944	1000.42	1590.29	1109.55	93.86	1402.02	1241.37	954.57	1146.78	9/21/07
39.17	948	1006.34	1590.96	1117.63	93.86	1402.20	1242.78	954.57	1147.14	9/21/07
39.33	952	1012.36	1591.72	1126.10	93.86	1402.82	1244.24	954.84	1147.64	9/21/07
39.50	956	1018.24	1592.39	1134.71	93.86	1403.18	1245.60	954.93	1147.96	9/21/07
39.67	960	1024.35	1593.19	1143.94	93.86	1403.53	1247.15	955.11	1148.55	9/21/07
39.83	964	1030.55	1594.09	1153.49	93.86	1404.15	1248.88	955.42	1149.01	9/21/07
40.00	968	1036.20	1594.71	1162.76	93.86	1404.33	1250.11	955.47	1149.33	9/21/07
40.17	972	1041.95	1595.34	1172.44	93.86	1404.51	1251.61	955.47	1149.83	9/21/07

Table D.7 continued

40.33	976	1047.52	1596.01	1182.07	93.86	1405.13	1253.16	955.47	1150.14	9/21/07
40.50	980	1052.86	1596.41	1191.75	93.86	1405.22	1254.48	955.47	1150.24	9/21/07
40.67	984	1058.43	1597.17	1202.01	93.86	1405.44	1256.02	955.47	1150.60	9/21/07
40.83	988	1064.18	1597.93	1212.62	93.86	1406.02	1257.84	955.47	1151.19	9/21/07
41.00	992	1069.70	1598.56	1223.11	93.86	1406.33	1259.44	955.47	1151.46	9/21/07
41.17	996	1075.22	1599.27	1233.99	93.86	1406.68	1261.16	955.47	1151.87	9/21/07
41.33	1000	1080.34	1599.76	1244.87	93.86	1406.95	1262.94	955.51	1152.24	9/21/07
41.50	1004	1085.68	1600.43	1256.11	93.86	1407.26	1264.62	955.51	1152.60	9/21/07
41.67	1008	1091.25	1601.15	1267.71	93.86	1407.93	1266.49	955.74	1153.15	9/21/07
41.83	1012	1096.82	1601.91	1279.66	93.86	1408.41	1268.35	955.96	1153.69	9/21/07
42.00	1016	1102.12	1602.49	1291.52	93.86	1408.64	1269.90	956.01	1153.92	9/21/07
42.17	1020	1107.28	1602.85	1303.56	93.86	1408.77	1271.45	956.01	1154.19	9/21/07
42.33	1024	1112.31	1603.29	1315.74	93.86	1409.17	1272.81	956.01	1154.47	9/21/07
42.50	1028	1117.20	1603.56	1327.92	93.86	1409.26	1273.77	956.01	1154.47	9/21/07
42.67	1032	1122.28	1604.01	1340.89	93.86	1409.26	1274.77	956.01	1154.65	9/21/07
42.83	1036	1127.44	1604.50	1354.59	93.86	1409.92	1275.54	956.01	1154.69	9/21/07
43.00	1040	1132.42	1604.99	1368.50	93.86	1410.06	1275.86	956.01	1154.69	9/21/07
43.17	1044	1137.41	1605.35	1382.42	93.86	1410.24	1276.22	956.01	1154.79	9/21/07
43.33	1048	1141.85	1605.40	1396.15	93.86	1410.41	1276.54	956.01	1154.97	9/21/07
43.50	1052	1146.93	1605.93	1409.62	93.86	1410.41	1276.73	956.01	1155.33	9/21/07
43.67	1056	1152.27	1606.60	1423.23	93.86	1411.08	1276.91	956.01	1155.92	9/21/07
43.83	1060	1157.79	1607.41	1437.50	93.86	1411.74	1277.36	956.01	1156.51	9/21/07
44.00	1064	1163.22	1607.94	1451.37	93.86	1412.28	1278.00	956.01	1156.97	9/21/07
44.17	1068	1168.30	1608.48	1464.97	93.86	1412.68	1278.45	956.01	1157.33	9/21/07
44.33	1072	1173.55	1609.02	1478.08	93.86	1413.03	1278.82	956.01	1157.70	9/21/07
44.50	1076	1178.94	1609.64	1489.59	93.86	1413.48	1279.32	956.01	1158.11	9/21/07
44.67	1080	1184.64	1610.36	1499.89	93.86	1414.10	1279.96	956.01	1158.70	9/21/07
44.83	1084	1190.34	1610.98	1510.29	93.86	1414.85	1280.64	956.46	1159.38	9/21/07
45.00	1088	1195.87	1611.47	1520.54	93.86	1415.39	1281.23	956.77	1159.93	9/21/07
45.17	1092	1201.57	1612.01	1530.93	93.86	1415.92	1281.82	957.04	1160.43	9/21/07
45.33	1096	1207.45	1612.59	1541.33	93.86	1416.14	1282.41	957.26	1160.93	9/21/07

Table D.7 continued

45.50	1100	1213.11	1612.86	1551.63	93.86	1416.72	1282.82	957.31	1161.20	9/21/07
45.67	1104	1219.04	1613.40	1562.29	93.86	1417.25	1283.28	957.49	1161.66	9/21/07
45.83	1108	1224.83	1613.75	1572.81	93.86	1417.65	1283.69	957.62	1161.97	9/21/07
46.00	1112	1230.66	1614.11	1583.30	93.86	1417.96	1284.01	957.62	1162.16	9/21/07
46.17	1116	1236.73	1614.47	1594.00	93.86	1418.49	1284.46	957.67	1162.16	9/21/07
46.33	1120	1242.65	1614.78	1604.39	93.86	1418.94	1284.82	957.80	1162.84	9/21/07
46.50	1124	1248.62	1615.18	1614.69	93.86	1419.38	1285.10	957.80	1163.16	9/21/07
46.67	1128	1255.18	1615.72	1625.09	93.86	1420.05	1285.60	957.94	1163.66	9/21/07
46.83	1132	1262.00	1616.39	1635.12	94.04	1421.07	1286.42	958.57	1164.61	9/21/07
47.00	1136	1268.92	1616.97	1643.91	94.68	1421.56	1286.92	958.92	1165.11	9/21/07
47.17	1140	1276.15	1617.69	1651.85	95.36	1422.67	1287.65	959.46	1165.93	9/21/07
47.33	1144	1282.97	1618.18	1659.12	95.63	1423.38	1288.05	959.69	1166.39	9/21/07
47.50	1148	1289.21	1618.36	1665.85	95.63	1423.51	1288.10	959.69	1166.39	9/21/07
47.67	1152	1295.95	1618.89	1672.63	95.63	1423.91	1288.10	959.69	1166.43	9/21/07
47.83	1156	1302.95	1619.43	1679.23	95.63	1424.44	1288.10	959.69	1166.62	9/21/07
48.00	1160	1309.82	1619.88	1685.12	95.63	1424.67	1288.10	959.69	1166.62	9/21/07
48.17	1164	1316.83	1620.55	1690.74	95.63	1425.24	1288.10	959.69	1166.71	9/21/07
48.33	1168	1323.74	1621.13	1695.51	95.63	1425.86	1288.24	959.69	1166.89	9/21/07
48.50	1172	1330.84	1621.93	1699.79	95.63	1426.44	1288.24	959.69	1166.89	9/21/07
48.67	1176	1338.51	1622.92	1703.85	95.63	1427.55	1288.65	959.69	1167.48	9/21/07
48.83	1180	1346.33	1623.81	1707.42	95.63	1428.71	1289.10	960.14	1168.07	9/21/07
49.00	1184	1353.51	1624.44	1709.96	95.63	1429.37	1289.15	960.14	1168.21	9/21/07
49.17	1188	1360.83	1624.93	1711.92	95.63	1430.13	1289.15	960.32	1168.30	9/21/07
49.33	1192	1368.10	1625.42	1713.08	95.63	1431.01	1289.28	960.59	1168.48	9/21/07
49.50	1196	1375.47	1625.87	1713.93	95.63	1431.90	1289.33	960.77	1168.57	9/21/07
49.67	1200	1383.41	1626.45	1715.09	95.63	1433.32	1289.78	961.39	1169.16	9/21/07
49.83	1204	1390.87	1627.03	1716.07	95.63	1434.70	1290.15	961.93	1169.62	9/21/07
50.00	1208	1398.37	1627.39	1716.74	95.63	1435.90	1290.28	962.29	1169.80	9/21/07
50.17	1212	1405.60	1627.75	1717.36	95.63	1437.14	1290.33	962.74	1169.98	9/21/07
50.33	1216	1412.78	1628.06	1717.90	95.63	1438.52	1290.33	963.28	1170.21	9/21/07
50.50	1220	1419.47	1628.28	1718.34	95.63	1439.89	1290.65	963.82	1170.35	9/21/07

Table D.7 continued

50.67	1224	1425.80	1628.68	1719.10	96.22	1441.63	1291.01	964.72	1170.76	9/21/07
50.83	1228	1430.56	1629.09	1719.77	96.94	1443.45	1291.29	965.66	1171.07	9/21/07
51.00	1232	1434.02	1629.35	1720.35	97.44	1445.22	1291.42	966.65	1171.26	9/21/07
51.17	1236	1436.53	1629.62	1720.84	98.03	1447.13	1291.47	967.77	1171.39	9/21/07
51.33	1240	1438.15	1629.85	1721.33	98.53	1449.09	1291.51	968.98	1171.48	9/21/07
51.50	1244	1438.78	1630.03	1721.69	98.94	1451.04	1291.51	970.24	1171.48	9/21/07
51.67	1248	1439.36	1630.34	1722.31	99.71	1453.48	1291.60	971.90	1171.80	9/21/07
51.83	1252	1439.54	1630.70	1722.89	100.57	1456.19	1291.79	973.65	1172.12	9/21/07
52.00	1256	1439.58	1631.01	1723.29	101.34	1458.94	1291.83	975.22	1172.26	9/21/07
52.17	1260	1439.72	1631.28	1723.65	101.93	1461.74	1291.83	976.75	1172.35	9/21/07
52.33	1264	1439.85	1631.59	1724.05	102.83	1464.00	1291.92	978.28	1172.48	9/21/07
52.50	1268	1439.94	1631.81	1724.32	103.65	1465.38	1291.92	979.62	1172.53	9/21/07
52.67	1272	1440.35	1632.30	1725.03	104.87	1466.45	1292.29	981.06	1173.08	9/21/07
52.83	1276	1440.75	1632.75	1725.66	106.09	1466.98	1292.65	982.50	1173.53	9/21/07
53.00	1280	1440.89	1632.98	1725.88	107.00	1467.02	1292.65	983.22	1173.58	9/21/07
53.17	1284	1440.93	1633.06	1725.97	107.72	1467.02	1292.65	983.49	1173.58	9/21/07
53.33	1288	1440.93	1633.06	1725.97	108.40	1467.02	1292.65	983.49	1173.58	9/21/07
53.50	1292	1440.93	1633.11	1726.02	109.36	1467.02	1292.65	983.49	1173.58	9/21/07
53.67	1296	1441.02	1633.33	1726.37	110.49	1467.02	1292.65	983.62	1173.62	9/21/07

Table D.8 Respirometer Calculated Data: Case C Gas Production Rate

		Gas Production Rate (mL/hr)							
Days	Time (hrs)	W,S,N	W,M,S,N	W,M,S	W,S	M,S,N	M,S	S,N	M
	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	5.00	4.84	4.45	3.83	2.45	2.06	2.19	2.29
0.00	8	0.23	0.25	0.17	0.13	0.00	0.04	0.01	0.13
0.17	12	0.78	0.47	0.28	0.11	0.00	0.00	0.00	0.10
0.33	16	4.29	1.02	1.15	0.31	0.00	0.03	0.00	0.18
0.50	20	2.46	1.43	4.42	1.38	0.01	0.03	0.00	0.16
0.67	24	0.00	0.51	1.13	5.38	0.00	0.06	0.00	0.19
0.83	28	0.00	0.30	0.00	2.96	0.19	0.04	0.00	0.16
1.00	32	0.00	0.31	0.00	0.01	0.08	0.00	0.00	0.10
1.17	36	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.09
1.33	40	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.18
1.50	44	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.20
1.67	48	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.25
1.83	52	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.30
2.00	56	0.00	0.58	0.01	0.00	0.00	0.04	0.00	0.26
2.17	60	0.00	0.62	0.00	0.00	0.00	0.03	0.00	0.28
2.33	64	0.00	0.70	0.00	0.00	0.00	0.10	0.00	0.35
2.50	68	0.02	0.64	0.00	0.00	0.00	0.05	0.00	0.30
2.67	72	0.16	0.65	0.00	0.00	0.00	0.02	0.00	0.31
2.83	76	0.15	0.62	0.00	0.00	0.25	0.07	0.00	0.34
3.00	80	0.03	0.55	0.00	0.00	0.17	0.04	0.02	0.32
3.17	84	0.17	0.61	0.10	0.00	0.26	0.11	0.14	0.38
3.33	88	0.17	0.66	0.19	0.00	0.32	0.21	0.12	0.44
3.50	92	0.09	0.58	0.16	0.01	0.30	0.15	0.07	0.39
3.67	96	0.12	0.53	0.21	0.02	0.35	0.15	0.04	0.39
3.83	100	0.10	0.50	0.22	0.00	0.37	0.20	0.11	0.46
4.00	104	0.09	0.45	0.22	0.00	0.31	0.20	0.08	0.46
4.17	108	0.15	0.49	0.28	0.00	0.36	0.26	0.13	0.51
4.33	112	0.15	0.49	0.31	0.00	0.37	0.31	0.14	0.56
4.50	116	0.14	0.47	0.30	0.00	0.34	0.30	0.13	0.56
4.67	120	0.24	0.52	0.44	0.00	0.49	0.37	0.22	0.68
4.83	124	0.19	0.50	0.46	0.00	0.47	0.34	0.19	0.71
5.00	128	0.23	0.52	0.42	0.00	0.51	0.37	0.19	0.75
5.17	132	0.32	0.53	0.49	0.00	0.59	0.42	0.23	0.87
5.33	136	0.34	0.51	0.49	0.00	0.62	0.43	0.27	0.93
5.50	140	0.41	0.59	0.57	0.00	0.73	0.51	0.32	1.06
5.67	144	0.44	0.59	0.58	0.00	0.81	0.55	0.34	1.17
5.83	148	0.45	0.71	0.67	0.00	0.98	0.66	0.36	1.36
6.00	152	0.39	0.67	0.65	0.22	1.02	0.65	0.31	1.49
6.17	156	0.45	0.74	0.66	0.30	1.12	0.73	0.34	1.64
6.33	160	0.49	0.84	0.72	0.43	1.21	0.84	0.36	1.83
6.50	164	0.57	0.95	0.79	0.61	1.32	0.91	0.38	2.04
6.67	168	0.71	1.19	0.95	0.80	1.52	1.05	0.48	2.37
6.83	172	0.80	1.30	1.07	0.81	1.62	1.14	0.53	2.67

Table D.8 continued

7.00	176	0.68	1.31	1.00	0.45	1.63	1.08	0.45	2.80
7.17	180	0.85	1.53	1.26	0.19	1.93	1.30	0.58	3.19
7.33	184	0.93	1.69	1.37	0.02	2.10	1.41	0.62	3.50
7.50	188	1.06	1.83	1.54	0.04	2.25	1.50	0.66	3.82
7.67	192	1.24	2.14	1.90	0.00	2.57	1.73	0.84	4.25
7.83	196	1.40	2.40	2.14	0.00	2.75	1.87	0.93	4.63
8.00	200	1.39	2.50	2.25	0.01	2.83	1.87	0.89	4.84
8.17	204	1.64	2.80	2.60	0.00	3.14	2.05	1.01	5.21
8.33	208	1.84	3.11	2.96	0.00	3.41	2.24	1.11	5.56
8.50	212	1.92	3.32	3.22	0.00	3.52	2.25	1.12	5.71
8.67	216	2.03	3.45	3.50	0.00	3.65	2.29	1.16	5.81
8.83	220	2.31	3.80	3.98	0.00	3.89	2.49	1.30	5.97
9.00	224	2.43	3.96	4.23	0.00	3.94	2.46	1.33	5.93
9.17	228	2.65	4.20	4.55	0.00	4.06	2.49	1.42	5.83
9.33	232	2.88	4.43	4.90	0.00	4.19	2.53	1.50	5.65
9.50	236	3.07	4.59	5.11	0.00	4.23	2.50	1.56	5.35
9.67	240	3.42	4.83	5.46	0.00	4.42	2.54	1.74	5.01
9.83	244	3.67	5.09	5.51	0.00	4.51	2.53	1.82	4.61
10.00	248	3.80	5.08	5.35	0.00	4.45	2.43	1.80	3.94
10.17	252	3.87	5.10	5.12	0.00	4.47	2.27	1.87	3.45
10.33	256	3.97	5.06	4.73	0.00	4.58	2.17	1.90	2.95
10.50	260	3.94	4.91	4.18	0.00	4.55	1.97	1.90	2.55
10.67	264	4.02	4.87	3.58	0.01	4.66	1.90	2.01	2.42
10.83	268	3.95	4.61	2.75	0.00	4.58	1.83	2.04	2.35
11.00	272	3.67	4.16	1.64	0.00	4.33	1.54	1.91	2.10
11.17	276	3.49	3.68	0.66	0.00	4.13	1.40	1.89	2.00
11.33	280	3.19	3.25	0.27	0.00	4.04	1.36	1.89	2.01
11.50	284	2.88	2.72	0.19	0.00	3.85	1.29	1.81	1.95
11.67	288	2.64	2.37	0.20	0.13	3.90	1.34	1.76	1.96
11.83	292	2.13	1.85	0.23	0.25	3.84	1.46	1.83	2.01
12.00	296	1.52	1.40	0.21	0.15	3.62	1.44	1.71	1.87
12.17	300	0.94	1.26	0.28	0.10	3.50	1.58	1.72	1.89
12.33	304	0.29	1.23	0.30	0.09	3.32	1.74	1.76	1.86
12.50	308	0.15	1.27	0.37	0.09	3.08	1.83	1.84	1.89
12.67	312	0.19	1.35	0.50	0.10	2.94	2.08	2.05	2.01
12.83	316	0.16	1.42	0.56	0.22	2.81	2.20	2.14	1.96
13.00	320	0.00	1.33	0.48	0.05	2.46	2.11	2.09	1.89
13.17	324	0.00	1.50	0.60	0.06	2.39	2.18	2.25	1.95
13.33	328	0.00	1.66	0.70	0.05	2.33	2.25	2.30	2.00
13.50	332	0.00	1.90	0.87	0.06	2.29	2.28	2.37	2.12
13.67	336	0.01	2.19	1.05	0.08	2.27	2.33	2.44	2.25
13.83	340	0.09	2.46	1.19	0.18	2.18	2.36	2.48	2.30
14.00	344	0.07	2.67	1.26	0.11	1.92	2.29	2.45	2.14
14.17	348	0.06	2.85	1.37	0.10	1.86	2.29	2.48	1.91
14.33	352	0.08	3.07	1.51	0.10	1.77	2.31	2.48	1.77
14.50	356	0.08	3.19	1.61	0.09	1.64	2.25	2.46	1.63
14.67	360	0.09	3.25	1.73	0.03	1.55	2.16	2.45	1.53
14.83	364	0.20	3.44	2.02	0.00	1.69	2.35	2.53	1.61

Table D.8 continued

15.00	368	0.10	3.35	2.04	0.02	1.54	2.17	2.22	1.46
15.17	372	0.08	3.29	2.18	0.07	1.52	2.17	2.04	1.47
15.33	376	0.13	3.33	2.33	0.07	1.56	2.17	1.85	1.50
15.50	380	0.10	3.32	2.44	0.06	1.55	2.10	1.54	1.49
15.67	384	0.21	3.35	2.60	0.26	1.62	2.13	1.46	1.60
15.83	388	0.26	3.47	2.70	0.15	1.63	2.13	1.29	1.65
16.00	392	0.23	3.33	2.74	0.11	1.61	2.09	1.08	1.65
16.17	396	0.26	3.25	2.76	0.09	1.61	2.04	0.92	1.66
16.33	400	0.29	3.17	2.78	0.10	1.69	2.05	0.83	1.60
16.50	404	0.34	3.14	2.86	0.10	1.71	1.98	0.76	1.33
16.67	408	0.44	3.08	2.92	0.09	1.95	2.04	0.76	1.19
16.83	412	0.51	3.01	2.97	0.08	2.20	2.01	0.78	1.11
17.00	416	0.48	2.82	2.96	0.13	2.41	1.89	0.72	1.06
17.17	420	0.49	2.67	2.86	0.16	2.68	1.75	0.66	1.06
17.33	424	0.54	2.54	2.87	0.12	2.96	1.60	0.65	1.11
17.50	428	0.56	2.36	2.80	0.09	3.00	1.49	0.63	1.15
17.67	432	0.66	2.29	2.85	0.16	2.53	1.49	0.69	1.29
17.83	436	0.73	2.13	2.81	0.16	1.64	1.38	0.69	1.37
18.00	440	0.69	1.86	2.62	0.05	0.91	1.21	0.58	1.09
18.17	444	0.76	1.75	2.57	0.11	0.66	1.15	0.57	0.81
18.33	448	0.78	1.56	2.44	0.07	0.57	1.09	0.57	0.66
18.50	452	0.80	1.42	2.36	0.09	0.58	1.04	0.55	0.58
18.67	456	0.93	1.38	2.33	0.10	0.63	1.04	0.60	0.61
18.83	460	0.95	1.32	2.25	0.09	0.63	1.01	0.62	0.68
19.00	464	0.91	1.21	2.16	0.10	0.61	0.88	0.55	0.59
19.17	468	0.90	1.12	2.32	0.15	0.59	0.74	0.52	0.57
19.33	472	0.95	1.08	2.14	0.08	0.61	0.76	0.56	0.60
19.50	476	1.00	1.03	1.82	0.05	0.61	0.64	0.52	0.58
19.67	480	1.17	1.14	1.77	0.15	0.80	0.66	0.64	0.70
19.83	484	1.18	1.10	1.59	0.13	0.83	0.63	0.62	0.72
20.00	488	1.18	1.04	1.39	0.06	0.80	0.52	0.55	0.66
20.17	492	1.24	1.00	1.24	0.06	0.84	0.49	0.57	0.70
20.33	496	1.34	1.10	1.10	0.08	1.00	0.56	0.61	0.73
20.50	500	1.34	1.06	0.91	0.05	1.04	0.51	0.59	0.73
20.67	504	1.48	1.17	0.80	0.08	1.22	0.59	0.65	0.88
20.83	508	1.61	1.29	0.72	0.14	1.39	0.66	0.73	0.96
21.00	512	1.57	1.25	0.55	0.08	1.39	0.68	0.69	0.90
21.17	516	1.67	1.34	0.48	0.09	1.55	0.75	0.72	0.98
21.33	520	1.82	1.49	0.47	0.13	1.75	0.89	0.80	1.06
21.50	524	1.89	1.69	0.46	0.13	1.85	1.00	0.82	1.13
21.67	528	1.99	1.87	0.46	0.14	2.02	1.09	0.85	1.17
21.83	532	2.00	2.00	0.40	0.10	2.10	1.32	0.74	1.21
22.00	536	2.02	2.10	0.28	0.01	2.11	1.34	0.76	1.16
22.17	540	2.07	2.19	0.25	0.00	2.27	1.47	0.80	1.18
22.33	544	2.16	2.14	0.30	0.00	2.50	1.75	0.89	1.33
22.50	548	2.27	1.76	0.32	0.00	2.62	1.73	0.92	1.35
22.67	552	2.40	1.27	0.43	0.00	2.83	1.69	1.00	1.50
22.83	556	2.49	0.78	0.44	0.00	3.02	1.42	1.09	1.59

Table D.8 continued

23.00	560	2.51	0.48	0.42	0.00	3.12	1.05	1.15	1.61
23.17	564	2.66	0.47	0.46	0.00	3.29	0.79	1.40	1.71
23.33	568	2.66	0.44	0.48	0.00	3.34	0.55	1.44	1.78
23.50	572	2.63	0.38	0.46	0.00	3.38	0.36	1.48	1.82
23.67	576	2.71	0.43	0.53	0.09	3.56	0.40	1.62	1.97
23.83	580	2.68	0.42	0.53	0.14	3.63	0.42	1.69	2.03
24.00	584	2.60	0.34	0.44	0.07	3.62	0.36	1.67	1.97
24.17	588	2.51	0.27	0.43	0.02	3.73	0.39	1.73	2.01
24.33	592	2.52	0.39	0.47	0.08	3.91	0.51	1.88	2.13
24.50	596	2.35	0.38	0.48	0.06	3.94	0.49	1.96	2.16
24.67	600	2.34	0.47	0.56	0.07	4.08	0.59	2.13	2.22
24.83	604	2.25	0.51	0.63	0.07	4.23	0.70	2.32	2.24
25.00	608	1.99	0.46	0.56	0.06	4.16	0.69	2.36	2.10
25.17	612	1.93	0.47	0.66	0.23	4.35	0.83	2.58	2.07
25.33	616	1.71	0.62	0.61	0.13	4.33	0.89	2.72	1.66
25.50	620	1.58	0.56	0.62	0.09	4.34	0.80	2.78	0.98
25.67	624	1.52	0.68	0.69	0.11	4.40	0.97	2.77	0.64
25.83	628	1.30	0.66	0.63	0.05	4.05	1.00	2.65	0.39
26.00	632	0.84	0.55	0.51	0.04	3.09	0.89	2.38	0.25
26.17	636	0.69	0.63	0.60	0.04	3.20	0.91	2.30	0.27
26.33	640	0.52	0.43	0.61	0.00	3.22	0.99	2.18	0.30
26.50	644	0.44	0.53	0.62	0.00	3.14	0.90	2.03	0.26
26.67	648	0.49	0.64	0.76	0.00	3.08	0.95	2.00	0.33
26.83	652	0.41	0.57	0.79	0.00	2.66	0.97	1.94	0.38
27.00	656	0.47	0.54	0.85	0.00	1.32	0.94	1.86	0.37
27.17	660	0.44	0.69	0.89	0.00	0.74	0.96	1.83	0.38
27.33	664	0.43	0.60	0.95	0.00	0.49	0.99	1.88	0.41
27.50	668	0.44	0.69	1.01	0.00	0.32	1.02	1.89	0.38
27.67	672	0.50	0.67	1.09	0.00	0.33	1.13	1.99	0.42
27.83	676	0.49	0.70	0.88	0.00	0.36	1.25	2.05	0.44
28.00	680	0.43	0.57	0.72	0.00	0.24	1.23	1.99	0.30
28.17	684	0.41	0.49	0.64	0.00	0.25	1.33	2.02	0.27
28.33	688	0.45	0.57	0.63	0.15	0.32	1.50	2.09	0.30
28.50	692	0.31	0.49	0.49	0.05	0.24	1.49	1.94	0.16
28.67	696	0.33	0.48	0.46	0.02	0.21	1.53	1.83	0.11
28.83	700	0.28	0.55	0.41	0.01	0.22	1.63	1.74	0.11
29.00	704	0.25	0.51	0.34	0.00	0.20	1.68	1.65	0.07
29.17	708	0.25	0.56	0.34	0.00	0.22	1.84	1.58	0.09
29.33	712	0.24	0.57	0.29	0.00	0.20	1.94	1.44	0.09
29.50	716	0.27	0.62	0.26	0.00	0.22	2.01	1.48	0.00
29.67	720	0.36	0.76	0.36	0.00	0.29	2.23	1.56	0.22
29.83	724	0.34	0.84	0.39	0.00	0.30	2.29	1.58	0.23
30.00	728	0.45	0.85	0.35	0.00	0.36	2.29	1.54	0.18
30.17	732	0.40	0.91	0.33	0.00	0.28	2.29	1.53	0.16
30.33	736	0.38	0.95	0.34	0.00	0.36	2.31	1.51	0.16
30.50	740	0.41	1.01	0.34	0.00	0.29	2.35	1.45	0.16
30.67	744	0.46	1.15	0.39	0.00	0.38	2.48	1.61	0.23
30.83	748	0.57	1.23	0.46	0.00	0.37	2.62	1.63	0.27

Table D.8 continued

31.00	752	0.48	1.29	0.36	0.00	0.34	2.59	1.54	0.19
31.17	756	0.52	1.36	0.37	0.00	0.35	2.66	1.55	0.20
31.33	760	0.51	1.39	0.36	0.00	0.33	2.71	1.53	0.17
31.50	764	0.54	1.46	0.37	0.00	0.37	2.79	1.54	0.19
31.67	768	0.64	1.65	0.46	0.00	0.39	2.91	1.62	0.26
31.83	772	0.64	1.70	0.47	0.00	0.35	3.03	1.64	0.29
32.00	776	0.64	1.68	0.42	0.00	0.32	2.99	1.52	0.23
32.17	780	0.63	1.81	0.44	0.00	0.25	3.03	1.49	0.23
32.33	784	0.66	1.81	0.45	0.00	0.28	3.14	1.41	0.26
32.50	788	0.62	1.87	0.41	0.00	0.14	3.13	1.09	0.22
32.67	792	0.75	2.10	0.53	0.00	0.25	3.30	0.92	0.33
32.83	796	0.66	2.21	0.56	0.11	0.22	3.36	0.74	0.33
33.00	800	0.65	2.21	0.47	0.10	0.17	3.28	0.39	0.24
33.17	804	0.59	2.32	0.50	0.05	0.14	3.31	0.24	0.25
33.33	808	0.53	2.25	0.48	0.06	0.14	3.34	0.13	0.27
33.50	812	0.58	2.27	0.56	0.08	0.13	3.37	0.17	0.33
33.67	816	0.54	2.46	0.57	0.07	0.19	3.41	0.12	0.33
33.83	820	0.52	2.58	0.57	0.07	0.14	3.40	0.10	0.33
34.00	824	0.42	2.57	0.51	0.04	0.04	3.23	0.01	0.22
34.17	828	0.49	2.71	0.47	0.03	0.07	3.19	0.01	0.25
34.33	832	0.54	2.75	0.55	0.04	0.10	3.07	0.03	0.27
34.50	836	0.54	2.82	0.61	0.04	0.09	2.79	0.02	0.28
34.67	840	0.73	2.98	0.79	0.05	0.21	2.22	0.12	0.38
34.83	844	0.86	3.15	0.79	0.06	0.22	1.31	0.15	0.42
35.00	848	0.90	3.24	0.75	0.03	0.15	0.73	0.02	0.35
35.17	852	1.00	3.33	0.76	0.03	0.01	0.38	0.10	0.30
35.33	856	1.10	3.35	0.82	0.03	0.18	0.32	0.10	0.40
35.50	860	1.24	3.40	0.89	0.04	0.11	0.26	0.09	0.39
35.67	864	1.41	3.51	0.96	0.17	0.13	0.33	0.13	0.49
35.83	868	1.56	3.55	1.03	0.13	0.20	0.34	0.17	0.53
36.00	872	1.55	3.54	0.97	0.05	0.11	0.27	0.09	0.44
36.17	876	1.64	3.71	0.99	0.06	0.14	0.14	0.10	0.49
36.33	880	1.51	3.47	0.87	0.01	0.06	0.27	0.02	0.35
36.50	884	1.48	3.42	0.86	0.00	0.00	0.15	0.00	0.34
36.67	888	1.56	3.33	1.03	0.00	0.00	0.23	0.00	0.45
36.83	892	1.58	3.34	1.10	0.00	0.06	0.31	0.00	0.55
37.00	896	1.55	3.00	1.15	0.00	0.11	0.30	0.00	0.53
37.17	900	1.51	2.54	1.19	0.00	0.00	0.32	0.00	0.55
37.33	904	1.50	1.53	1.24	0.00	0.11	0.32	0.00	0.57
37.50	908	1.48	1.00	1.28	0.00	0.00	0.31	0.00	0.56
37.67	912	1.57	0.74	1.51	0.00	0.19	0.44	0.00	0.59
37.83	916	1.59	0.55	1.59	0.00	0.17	0.47	0.11	0.40
38.00	920	1.50	0.41	1.57	0.00	0.06	0.35	0.04	0.19
38.17	924	1.48	0.32	1.61	0.00	0.12	0.35	0.02	0.14
38.33	928	1.51	0.37	1.73	0.00	0.13	0.42	0.09	0.19
38.50	932	1.52	0.29	1.76	0.00	0.06	0.38	0.03	0.14
38.67	936	1.66	0.35	1.97	0.00	0.24	0.48	0.15	0.25
38.83	940	1.59	0.28	2.06	0.00	0.14	0.47	0.12	0.24

Table D.8 continued

39.00	944	1.57	0.26	2.04	0.00	0.14	0.40	0.03	0.15
39.17	948	1.48	0.17	2.02	0.00	0.05	0.35	0.00	0.09
39.33	952	1.51	0.19	2.12	0.00	0.16	0.37	0.07	0.13
39.50	956	1.47	0.17	2.15	0.00	0.09	0.34	0.02	0.08
39.67	960	1.53	0.20	2.31	0.00	0.09	0.39	0.04	0.15
39.83	964	1.55	0.23	2.39	0.00	0.16	0.43	0.08	0.12
40.00	968	1.41	0.15	2.32	0.00	0.05	0.31	0.01	0.08
40.17	972	1.44	0.16	2.42	0.00	0.04	0.38	0.00	0.13
40.33	976	1.39	0.17	2.41	0.00	0.16	0.39	0.00	0.08
40.50	980	1.33	0.10	2.42	0.00	0.02	0.33	0.00	0.03
40.67	984	1.39	0.19	2.57	0.00	0.06	0.38	0.00	0.09
40.83	988	1.44	0.19	2.65	0.00	0.14	0.45	0.00	0.15
41.00	992	1.38	0.16	2.62	0.00	0.08	0.40	0.00	0.07
41.17	996	1.38	0.18	2.72	0.00	0.09	0.43	0.00	0.10
41.33	1000	1.28	0.12	2.72	0.00	0.07	0.44	0.01	0.09
41.50	1004	1.34	0.17	2.81	0.00	0.08	0.42	0.00	0.09
41.67	1008	1.39	0.18	2.90	0.00	0.17	0.47	0.06	0.14
41.83	1012	1.39	0.19	2.99	0.00	0.12	0.46	0.06	0.13
42.00	1016	1.32	0.14	2.96	0.00	0.06	0.39	0.01	0.06
42.17	1020	1.29	0.09	3.01	0.00	0.03	0.39	0.00	0.07
42.33	1024	1.26	0.11	3.05	0.00	0.10	0.34	0.00	0.07
42.50	1028	1.22	0.07	3.04	0.00	0.02	0.24	0.00	0.00
42.67	1032	1.27	0.11	3.24	0.00	0.00	0.25	0.00	0.05
42.83	1036	1.29	0.12	3.43	0.00	0.17	0.19	0.00	0.01
43.00	1040	1.25	0.12	3.48	0.00	0.03	0.08	0.00	0.00
43.17	1044	1.25	0.09	3.48	0.00	0.05	0.09	0.00	0.03
43.33	1048	1.11	0.01	3.43	0.00	0.04	0.08	0.00	0.04
43.50	1052	1.27	0.13	3.37	0.00	0.00	0.05	0.00	0.09
43.67	1056	1.33	0.17	3.40	0.00	0.17	0.05	0.00	0.15
43.83	1060	1.38	0.20	3.57	0.00	0.16	0.11	0.00	0.15
44.00	1064	1.36	0.13	3.47	0.00	0.13	0.16	0.00	0.11
44.17	1068	1.27	0.13	3.40	0.00	0.10	0.11	0.00	0.09
44.33	1072	1.31	0.14	3.28	0.00	0.09	0.09	0.00	0.09
44.50	1076	1.35	0.15	2.88	0.00	0.11	0.13	0.00	0.10
44.67	1080	1.42	0.18	2.57	0.00	0.16	0.16	0.00	0.15
44.83	1084	1.43	0.15	2.60	0.00	0.19	0.17	0.11	0.17
45.00	1088	1.38	0.12	2.56	0.00	0.13	0.15	0.08	0.14
45.17	1092	1.43	0.13	2.60	0.00	0.13	0.15	0.07	0.13
45.33	1096	1.47	0.15	2.60	0.00	0.06	0.15	0.06	0.13
45.50	1100	1.41	0.07	2.57	0.00	0.14	0.10	0.01	0.07
45.67	1104	1.48	0.13	2.66	0.00	0.13	0.12	0.04	0.12
45.83	1108	1.45	0.09	2.63	0.00	0.10	0.10	0.03	0.08
46.00	1112	1.46	0.09	2.62	0.00	0.08	0.08	0.00	0.05
46.17	1116	1.52	0.09	2.68	0.00	0.13	0.11	0.01	0.00
46.33	1120	1.48	0.08	2.60	0.00	0.11	0.09	0.03	0.17
46.50	1124	1.49	0.10	2.57	0.00	0.11	0.07	0.00	0.08
46.67	1128	1.64	0.13	2.60	0.00	0.17	0.13	0.04	0.13
46.83	1132	1.70	0.17	2.51	0.04	0.26	0.21	0.16	0.24

Table D.8 continued

47.00	1136	1.73	0.14	2.20	0.16	0.12	0.13	0.09	0.13
47.17	1140	1.81	0.18	1.99	0.17	0.28	0.18	0.14	0.20
47.33	1144	1.70	0.12	1.82	0.07	0.18	0.10	0.06	0.12
47.50	1148	1.56	0.05	1.68	0.00	0.03	0.01	0.00	0.00
47.67	1152	1.69	0.13	1.69	0.00	0.10	0.00	0.00	0.01
47.83	1156	1.75	0.13	1.65	0.00	0.13	0.00	0.00	0.05
48.00	1160	1.72	0.11	1.47	0.00	0.06	0.00	0.00	0.00
48.17	1164	1.75	0.17	1.40	0.00	0.14	0.00	0.00	0.02
48.33	1168	1.73	0.14	1.19	0.00	0.16	0.04	0.00	0.05
48.50	1172	1.77	0.20	1.07	0.00	0.14	0.00	0.00	0.00
48.67	1176	1.92	0.25	1.02	0.00	0.28	0.10	0.00	0.15
48.83	1180	1.95	0.22	0.89	0.00	0.29	0.11	0.11	0.15
49.00	1184	1.80	0.16	0.63	0.00	0.17	0.01	0.00	0.03
49.17	1188	1.83	0.12	0.49	0.00	0.19	0.00	0.05	0.02
49.33	1192	1.82	0.12	0.29	0.00	0.22	0.03	0.07	0.05
49.50	1196	1.84	0.11	0.21	0.00	0.22	0.01	0.04	0.02
49.67	1200	1.99	0.14	0.29	0.00	0.36	0.11	0.16	0.15
49.83	1204	1.86	0.15	0.24	0.00	0.34	0.09	0.14	0.12
50.00	1208	1.88	0.09	0.17	0.00	0.30	0.03	0.09	0.05
50.17	1212	1.81	0.09	0.16	0.00	0.31	0.01	0.11	0.05
50.33	1216	1.80	0.08	0.13	0.00	0.34	0.00	0.13	0.06
50.50	1220	1.67	0.06	0.11	0.00	0.34	0.08	0.14	0.04
50.67	1224	1.58	0.10	0.19	0.15	0.44	0.09	0.22	0.10
50.83	1228	1.19	0.10	0.17	0.18	0.45	0.07	0.23	0.08
51.00	1232	0.87	0.06	0.15	0.13	0.44	0.03	0.25	0.05
51.17	1236	0.63	0.07	0.12	0.15	0.48	0.01	0.28	0.03
51.33	1240	0.41	0.06	0.12	0.13	0.49	0.01	0.30	0.02
51.50	1244	0.16	0.05	0.09	0.10	0.49	0.00	0.31	0.00
51.67	1248	0.14	0.08	0.15	0.19	0.61	0.02	0.41	0.08
51.83	1252	0.05	0.09	0.15	0.22	0.68	0.05	0.44	0.08
52.00	1256	0.01	0.08	0.10	0.19	0.69	0.01	0.39	0.04
52.17	1260	0.04	0.07	0.09	0.15	0.70	0.00	0.38	0.02
52.33	1264	0.03	0.08	0.10	0.23	0.56	0.02	0.38	0.03
52.50	1268	0.02	0.06	0.07	0.20	0.35	0.00	0.34	0.01
52.67	1272	0.10	0.12	0.18	0.31	0.27	0.09	0.36	0.14
52.83	1276	0.10	0.11	0.16	0.31	0.13	0.09	0.36	0.11
53.00	1280	0.03	0.06	0.06	0.23	0.01	0.00	0.18	0.01
53.17	1284	0.01	0.02	0.02	0.18	0.00	0.00	0.07	0.00
53.33	1288	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00
53.50	1292	0.00	0.01	0.01	0.24	0.00	0.00	0.00	0.00
53.67	1296	0.02	0.06	0.09	0.28	0.00	0.00	0.03	0.01

APPENDIX E

GAS CHROMATOGRAPH CALIBRATION CURVES

Table E.1 Gas Chromatograph Calibration Data – Methane

Sample Size (µL)	Peak time (min.)	Area	Height
100	5.622	290,824	19,131
75	5.792	231,558	14,555
50	5.943	154,392	10,120
50 (LD)	5.920	166,176	10,668
25	5.410	68,240	5,514

LD = lab duplicate

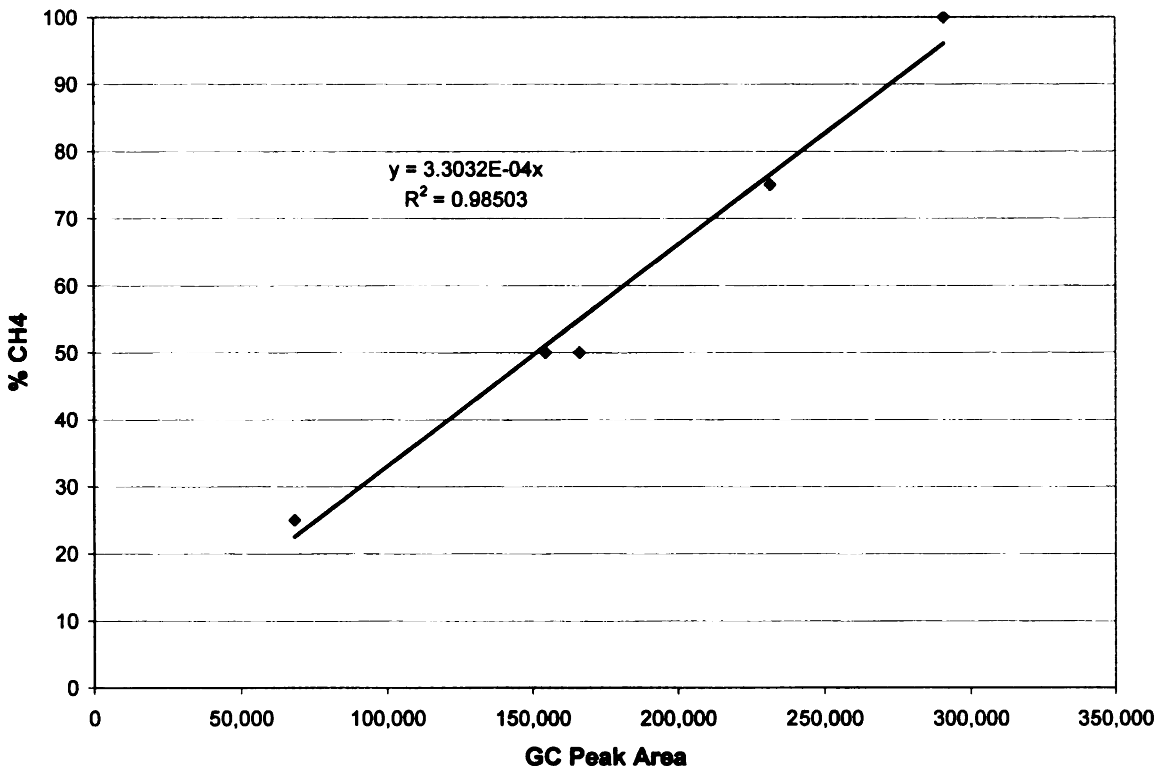

Figure E.1 Methane Calibration Curve

The trend line was set to a zero-intercept.

Table E.2 Gas Chromatograph Calibration Data – Carbon Dioxide

Sample Size (μL)	Peak time (min.)	Area	Height
100	8.170	391,603	20,814
100 (LD)	8.188	394,110	20,909
75	8.123	296,020	16,444
50	8.285	202,706	12,209
25	8.168	108,070	7,143
25 (LD)	8.517	121,700	6,926

LD = lab duplicate

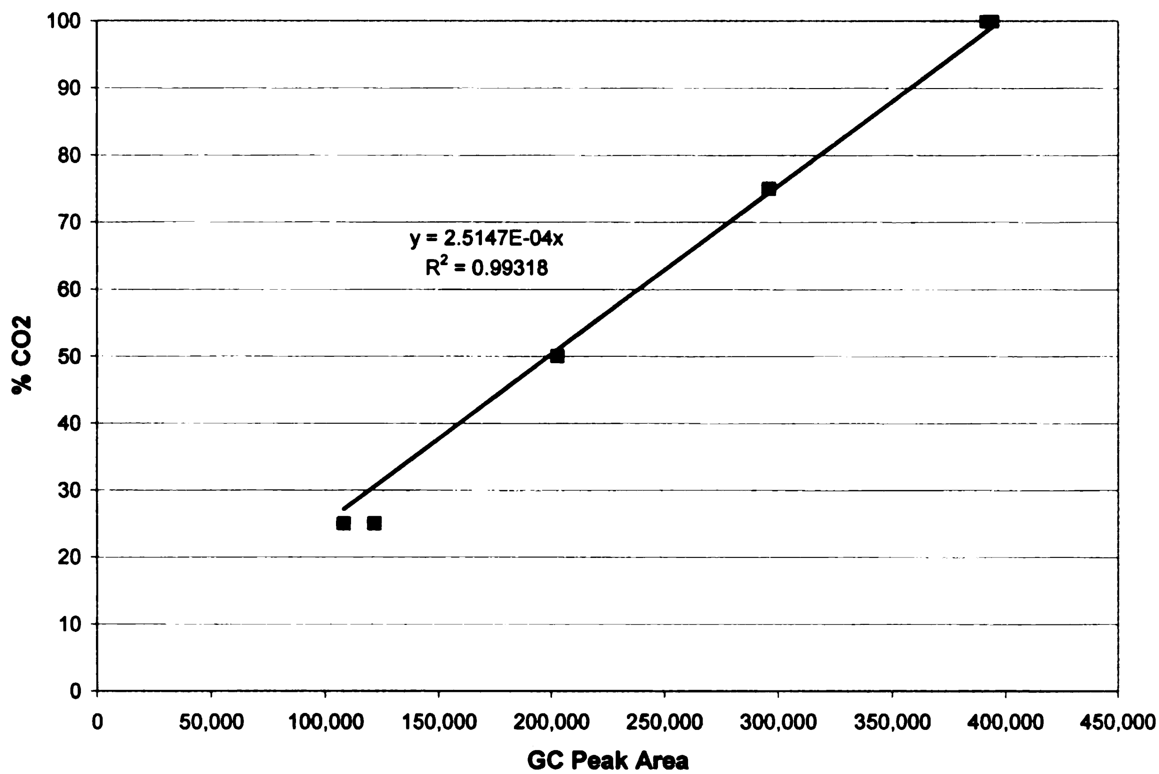

Figure E.2 Carbon Dioxide Calibration Curve

The trend line was set to a zero-intercept.

APPENDIX F

GAS CHROMATOGRAPHY DATA

Tables F.1, F.2, F.3 and F.4 present the gas chromatography data for Cases A, B-1, B-2 and C, respectively. The samples are listed in the order in which they were collected and analyzed, to maintain any evidence of situational effects. For example, it can be deduced that the methane present in the de-ionized water sample (Tables F.1, F.2 and F.3) is residual from the preceding sample.

"Isothermic" refers to a malfunction in the temperature ramp. These analyses were carried out at an oven temperature of 40°C rather than the regular 40°C to 120°C ramp. The only significant affect was a delayed peak time; the peak areas are comparable and therefore the results were judged valid. Readings were marked as 'below the detection limit' for those resulting in a negative value on a calibration curve.

The gas chromatograph was first operational at the very last days of Case A, for which calibration samples were also analyzed on 5/9/07. Equipment malfunctioned before the wastewater/seed/nutrients flask could be analyzed; the trial was over before the problems were remedied. For Case B-1, equipment malfunctioned following the fifth sample analysis (which also had an unidentified peak at 7.737 minutes). Testing was resumed several days later once the equipment was replaced. All flasks analyzed on the first day were re-sampled during this second day of testing. For Case C, gas samples from each flask were tested three days apart to test for methane fluctuations, which were considerable for some flasks (see also Table 4.5).

Table F.1 Gas Chromatography Data: Case A

Date	Sample ID	Sample Size (μL)	Peak Time	Area	%	(gas)
5/9/07	Wastewater, Seed (rep A)	100	5.421	188,866	62.4	CH_4
			8.028	37,212	9.4	CO_2
	Wastewater, Seed (rep B)	100	5.718	220,889	73.0	CH_4
			8.511	43,752	11.0	CO_2
5/10/07	CH_4	75	5.408	194,676	64.3	CH_4
	CO_2	75	5.571	1,276	0.4	CH_4
			7.915	286,545	72.1	CO_2
	CH_4	50	5.464	130,148	43.0	CH_4
			8.086	11,584	2.9	CO_2
	CO_2	50	7.949	193,482	48.7	CO_2
	Seed	100	5.425	195,331	64.5	CH_4
			8.065	33,827	8.5	CO_2
	1/2 (Wastewater, Seed, Nutrients)	100	5.783	142,342	47.0	CH_4
			8.555	35,201	8.9	CO_2
	Wastewater, Nutrients	100	5.788	113,680	37.6	CH_4
			8.548	19,387	4.9	CO_2
	De-ionized Water	100	5.849	78,102	25.8	CH_4

Table F.2 Gas Chromatography Data: Case B-1

Date	Sample	Sample Size (μL)	Peak Time	Area	% (gas)
6/1/07	CH_4 (isothermic)	50	6.868	156,819	51.8 CH_4
	CO_2	50	8.743	229,834	57.8 CO_2
	Wastewater, Seed, Nutrients	100	5.851	164,196	54.2 CH_4
			8.665	30,678	7.7 CO_2
	Wastewater, Seed (rep B)	100	5.803	144,777	47.8 CH_4
			8.602	21,276	5.4 CO_2
	1/2 (Wastewater, Seed, Nutrients)	100	5.815	59,234	19.6 CH_4
			7.737	*72,084*	*unknown*
			8.560	27,369	6.9 CO_2
6/7/07	CH_4 (isothermic)	50	6.983	136,269	45.0 CH_4
	CO_2	50	7.977	203,189	51.1 CO_2
	Wastewater, Seed, ½ Nutrients	100	5.724	214,741	70.9 CH_4
			8.511	26,599	6.7 CO_2
	Wastewater, Nutrients	100	5.722	14,538	4.8 CH_4
			8.397	15,953	4.0 CO_2
	Seed	100	5.695	207,282	68.5 CH_4
			8.492	14,105	3.5 CO_2
	Wastewater, Seed, Nutrients	100	5.700	197,445	65.2 CH_4
			8.477	30,746	7.7 CO_2
	1/2 (Wastewater, Seed, Nutrients)	100	5.689	134,902	44.6 CH_4
			8.431	15,592	3.9 CO_2
	De-ionized Water	100	5.817	17,254	5.7 CH_4
	Wastewater, Seed (rep B)	100	5.667	206,199	68.1 CH_4
			8.444	21,691	5.5 CO_2
	CH_4	75	5.673	223,581	73.9 CH_4
			8.477	4,586	1.2 CO_2

Table F.3 Gas Chromatography Data: Case B-2

Date	Sample	Sample Size (μL)	Peak Time	Area	%	(gas)
7/13/07	CO_2	50	9.199	210,200	52.9	CO_2
	CO_2	50	9.027	193,959	48.8	CO_2
	CH_4	50	5.798	121,183	40.0	CH_4
	CH_4 (isothermic)	75	7.337	237,352	78.4	CH_4
	Wastewater, Seed, Nutrients (rep A)	100	5.816	179,418	59.3	CH_4
			8.619	26,214	6.6	CO_2
	Wastewater, Seed	100	6.162	85,328	28.2	CH_4
			9.086	9,157	2.3	CO_2
	1/2 (Wastewater, Seed, Nutrients)	100	6.213	117,078	38.7	CH_4
			9.161	15,120	3.8	CO_2
	Seed, Nutrients	100	6.207	207,459	68.5	CH_4
			9.199	24,659	6.2	CO_2
	Seed	100	6.135	171,570	56.7	CH_4
			9.088	14,026	3.5	CO_2
	Wastewater, Seed, Nutrients (rep B)	100	6.113	226,356	74.8	CH_4
			9.079	31,383	7.9	CO_2
	De-ionized Water	100	6.257	16,982	5.6	CH_4

Table F.4 Gas Chromatography Data: Case C

Date	Sample	Sample Size (μL)	Peak Time	Area	%	(gas)
8/28/07	CH_4	50	6.66	170,266	56.2	CH_4
	CO_2	50	8.679	193,748	48.7	CO_2
	Manure, Seed	100	5.954	214,560	70.9	CH_4
			8.827	50,627	12.7	CO_2
	Manure, Seed, Nutrients	100	5.897	191,580	63.3	CH_4
			8.734	55,393	13.9	CO_2
	Wastewater, Manure, Seed, Nutrients	100	5.935	175,228	57.9	CH_4
			8.756	84,255	21.2	CO_2
	Wastewater, Seed, Nutrients	100	5.963	82,791	27.3	CH_4
			8.754	45,745	11.5	CO_2
	Manure	100	5.899	192,828	63.7	CH_4
			8.737	55,904	14.1	CO_2
	Wastewater, Manure, Seed	100	5.862	188,311	62.2	CH_4
			8.673	92,910	23.4	CO_2
	Seed, Nutrients	100	5.968	184,817	61.0	CH_4
			8.673	92,910	23.4	CO_2
	Wastewater, Seed	100	6.119	15,806	5.2	CH_4
			8.909	39,333	9.9	CO_2
8/31/07	CH_4	75	6.467	238,939	78.9	CH_4
	CO_2	50	9.305	184,557	46.4	CO_2
	Wastewater, Seed, Nutrients	100	6.060	190,201	62.8	CH_4
			9.105	114,662	28.8	CO_2
	Wastewater, Manure, Seed, Nutrients	100	6.393	120,978	40.0	CH_4
			9.405	57,958	14.6	CO_2
	Manure, Seed, Nutrients	100	6.372	234,058	77.3	CH_4
			9.428	73,680	18.5	CO_2
	Manure, Seed	100	6.321	235,355	77.7	CH_4
			9.372	60,933	15.3	CO_2
	Manure	100	6.355	213,580	70.5	CH_4
			9.398	77,922	19.6	CO_2

Table F.4 continued

8/31/07 continued	Seed, Nutrients	100	6.417	247,295	81.7	CH_4
			9.502	60,663	15.3	CO_2
	Wastewater, Seed	100	6.537	52,916	17.5	CH_4
			9.513	106,658	26.8	CO_2
	Wastewater, Manure, Seed	100	5.917	177,918	58.8	CH_4
			8.72	85,738	21.6	CO_2
	LD Manure, Seed	100	5.837	199,465	65.9	CH_4
			8.665	52,157	13.1	CO_2

LD = Lab Duplicate

APPENDIX G

QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance and quality control measures for the parameters analyzed in-house included lab duplicates and standards, when applicable. Lab duplicates were utilized in all testing. Table G.1 gives the average percent relative range of the lab duplicates for the various parameters. Standards were available for COD, total phosphorus and gas chromatography testing. Table G.2 gives the average percent recovery for these tests.

Table G.1 Percent Relative Range for Duplicates

Parameter	Average % Relative Range	Standard Deviation	No. of Analyses
Total Solids	6.57%	9.68%	4
Volatile Solids	2.50%	2.91%	3
COD	5.29%	3.39%	7
Total Phosphorus	8.64%	2.11%	3
Respirometer (cumulative gas)	2.74%	1.45%	3
Gas Chromatography	17.91%	1.79%	2

Table G.2 Percent Recovery for Standards

Parameter	Average % Recovery	Standard Deviation	No. of Analyses
COD	104.1%	2.7%	10
Total Phosphorus	94.8%	12.8%	3
Gas Chromatography	94.2% (CH_4) 101.0% (CO_2)	9.47% (CH_4) 8.52% (CO_2)	9 8

APPENDIX H

ANAEROBIC DIGESTION FEASIBILITY PROTOCOL

H.1 Processor's Goals and Objectives

Obtain the following information from the food processor and compare these goals and expectations with reasonable deliverables. See Appendix J for assessment worksheets.

1. Determine the processor's interest in anaerobic digestion.
   a. If a regional digester or co-digestion is being pursued, the protocol must be carried out for all contributors, and a representative substrate must be tested. Check all governing regulations, as some locales prohibit the mixing of certain waste streams.
   b. There should be no difference in assessment for individual treatment vs. energy objectives.
      i. An energy study may conclude 'only adequate for treatment'.
      ii. A treatment study may also conclude 'adequate for energy recovery.'
   c. Methane potential can only be an estimate; there are several determining factors in full-scale operation such as mixing effects which cannot be accounted for in lab-scale testing.
2. Determine the desired biogas applications. There are many indirect considerations for electric generation which should be addressed upfront. (This is outside the scope of this protocol. Consult an appropriate professional.) For example, if the electric

power will be sold back to a common grid, the utility company may assess significant hook-up fees.

3. Identify the discharge requirements: the COD (mg/L) and/or BOD (mg/L) as per regulations for applicable effluent discharge. BOD is the conventional measurement of wastewater quality, however COD is easier to measure and more representative of anaerobic treatment potential than BOD.

   a. It is assumed that fruit and vegetable processing waste streams contain below the regulated limits for nitrogen and phosphorus (and other nutrients and metals). If this is not the case, these nutrients must also be factored in at this step.

   b. The required COD or BOD discharge concentrations will be compared with waste stream concentrations to determine the degree of treatment required. If adequate treatment cannot be achieved by anaerobic digestion alone, an alternate treatment or additional aerobic unit must be considered. See Section H.3.2 to estimate treatment potential.

4. Assess the relative economic status of the project.

   a. Some operating costs and methane cost savings are discussed throughout the protocol. Digestion of any given waste may require regular addition of an alkalinity source, nitrogen, phosphorus or metals and thus, an added operating cost. This may be a significant or negligible cost depending on the nutrient and level of deficiency.

b. These considerations may be used to supplement a full cost-benefit analysis (which is beyond the scope of this protocol).

5. Determine the processor's timeline for operational treatment or compliance.

    a. This protocol may require several months for sampling and testing. Further pilot-scale testing may be recommended, which would require several months additional.

    b. Full-scale system design and permit applications may take over a year.

    c. Construction, start-up and stabilization may require over a year additional.

H.2 Plant Profile

Obtain the following information from the food processor. See Appendix J for plant assessment worksheets.

1. Determine the plant's average monthly energy usage (natural gas in thm/month, and/or electricity in kWh/month). This can be calculated from billing costs.

2. Identify the plant's wastewater streams (by commodity or location in the plant). Characterize the fluctuation in flow and COD loading throughout the year and average temperature of each stream.

   a. If necessary, convert the units of COD (or BOD) to kg/day and wastewater flow to m^3/day.

   b. Identify waste streams that are most appropriate for anaerobic digestion, with high soluble organic loading.

      i. Determine if streams currently may be combined to equilibrate COD and volume loadings or may be readily combined by installing piping. Alternately, consider if streams with low organic loading could be readily separated and diverted, such as storm water.

      ii. A high peak in volume or COD may require a large equalization tank, adding to construction costs.

3. Identify the commodities processed and the fluctuation in volume processed throughout the year. See Appendix I for assessment worksheets.

   a. Correlate this with the data from section H.1.2 above.

   b. If data for section H.1.2 is not available, the plant's commodity data and water use may be used to approximate ranges for BOD loading and waste stream flow using published data for each commodity (ex: gal/day per ton processed). Weight these accordingly for each commodity processing rate per year (tons/month * # of months/year).

4. List any known cleaners, sanitizers or chemical additives used in processing that may be present in the different waste streams. If certain compounds are only used in specific areas (waste streams) specify which.

    a. Compounds may include (but are not limited to):

    Oxidizing sanitizers

    - Hyperchlorites, chlorine, chloramines
    - Organic bromine
    - Iodine, alcohol-iodine, iodophors
    - Hydrogen peroxide, peroxy acids

    Biocides and non-oxidizing sanitizers

    - Organic acids (e.g. acetic acid, propionic acid, formic acid, carboxylic acids)
    - Acid anionic sanitizers
    - Acid-quat sanitizers
    - Quaternary ammonium compounds

    b. Any compounds present may serve as potential sources of toxicity that may interfere with anaerobic digestion. It may be possible for a full scale digester may acclimate and adapt to such toxicity.

c. If specific concentrations can be determined, compare the present levels to a known IC_{50} (inhibitive concentration) if available. See Blum and Speece (1991).

d. For concentrations near the IC_{50} level, anaerobic treatment and methane production may be severely retarded. An alternate wastewater treatment should be pursued if the chemical(s) of concern cannot be replaced with one(s) less toxic.

H.3 COD Conversion to Heat and Electric Potential

1. If historical plant data is unavailable (section H.2.3), analyze the processing plant's average daily wastewater COD concentration and daily water volume usage. Characterize COD levels for as many commodities as possible. If time does not permit testing of all commodities, consult published COD estimates to identify 'high' and 'low' COD level commodities in order to ensure that representative commodities are tested at the very least. Take samples during a transition period to include at least two commodities. Using results from only the 'worst' commodity (i.e. that with the highest COD) may provide overestimated results in methane potential.

   a. Test COD using Hach Method 8000.

      i. Collect field duplicates.

ii. Verify testing methods using lab duplicates. The percent difference should be less than 20%.

b. Compare test results against published commodity ranges. (*See* *Commodity Report and Categorization of Michigan crops*.)

2. Consider the average and peak COD loading ($kg/m^3/d$) and assume an appropriate reactor type based on Table H.1 below, with a given COD removal treatment efficiency (e.g. 80 to 90%):

Table H.1 Types of Anaerobic Digesters

Reactor Type	COD loading*	COD removal rates*
Contact (ANCP)**	1-5 $kg/m^3/d$	70-95%
Hybrids	5-15 $kg/m^3/d$	70-95%
UASB**	5-20 $kg/m^3/d$	80-95%
Filters	5-20 $kg/m^3/d$	70-90%
EFB**	10-40 $kg/m^3/d$	60-85%

*Totzke (2006)
** ANCP = Anaerobic Contact Process
UASB = Up-flow Anaerobic Sludge Blanket
EFB = Expanded/ fluidized bed

3. Calculate a COD removal rate (kg/d) based on reactor treatment efficiency using equation H.1.

COD removal rate (kg/d) = minimum %COD removal (%/ 100) * average COD influent (kg/m^3) * flow rate (m^3/d) [H.1]

4. Based on COD removal, calculate the heating and electric potentials.

a. For estimated heating potential see equation H.2 (Speece, 1996):

$$Btu/d = 12x10^{6}\ Btu / 1000\ kg\ COD\ removed * COD\ removal\ rate\ (kg/d) \quad [H.2]$$

b. For estimated electric wattage potential see equation H.3 (Speece, 1996):

$$MWhr = (1\ MW/10^{7}\ Btu) * (12x10^{6} / 1000\ kg\ COD\ removed) * COD\ removal\ rate\ (kg/d) * 24\ hr/d \quad [H.3]$$

5. Compare these results to the processor's energy needs (section H.1). If the results are appropriate for the processor's intended anaerobic applications, continue on to section H.4.

H.4 Substrate Characterization Tests

The COD conversions to Btu and MW estimates do not account for variability in substrate biodegradability. To properly assess the anaerobic digestibility of a given waste stream, several other parameters must be analyzed. Historical data should be available (often collected monthly and annually per regulations).

1. Retrieve historical wastewater effluent data for the past 1 to 2 years.

2. Collect wastewater effluent samples, throughout the season if possible. Samples must be representative of both the dominant commodity(s) and those with the highest COD loading (which may be more seasonal, e.g. pumpkins).

3. Test the samples for the parameters listed in Table H.2.

Table H.2 Substrate Characterization Analyses

Analysis	Method	Suggested Range	Source
pH	pH meter	6.5 to 8.2	Speece, 1996
Alkalinity	Hach 8203	2000 to 3000 mg/L $CaCO_3$	Speece, 1996
COD	Hach 8000 (EPA approved)	> 1000 mg/L COD	Speece, 1996
Total Nitrogen series	EPA-350.1, 353.2, 351.3, 350.2/351.3	3 to 5 mg/L N per 100 mg/L COD	Bouallagui et al., 2004b
Ammonia	EPA-350.1	> 40 to 70 mg/L NH_4 < 1500 mg/L NH_4	Speece, 1996 Calli, et al. 2005
Total Phosphorus	Hach 8190	0.5 to 1 mg/L P per 100 mg/L COD	Bouallagui et al., 2004b
Total Solids (TS)	Hach 8271 (EPA approved)	< 10% for batch tests	Carucci et al., 2005
Volatile Suspended Solids (VSS)	Hach 8158, 8164	Calculate VSS:TS. The higher, the better.	
Sulfide	EPA-376.2	> 2 mg/L S, <200 mg/L S	Isa et al., 1986
Sulfate	EPA-375.4	< 5000 mg/L SO_4 for treatment < 300 mg/L SO_4 for biogas applications	Isa et al., 1986

4. If processed commodities include foods high in polyphenols or long chain fatty acids (> 100 mg/L), then pretreatment may be required (see Chapter 2: Literature Review), which would raise capital and/or operating costs depending on the chosen treatment method.

a. High-phenol foods include (www.kirkmanlabs.com):

- Apricots
- Berries
- Cherries
- Dill
- Licorice (Anise)
- Mint
- Olives
- Oranges
- Pineapple
- Peppers
- Red grapes
- Tomatoes

5. Analyze the test results and assess the implications for the processor's goals as described below.

a. If pH is too low, then acetate production does not occur and methane will not be produced. If pH is too high, then less ammonia (NH_3) ionizes to ammonium (NH_4^+) and becomes toxic.

b. Estimate the alkalinity amendment required using equation H.4. This is only a rough estimate, and alkalinity production will not be accurately represented at a lab scale.

Added alkalinity mg/L /day = 10%(influent COD mg/L) – influent alkalinity mg/L

[H.4]

i. Low-protein waste will generate little to no alkalinity during digestion.

ii. Consider the cost of alkalinity treatment per year and include as an operating cost. Cost can vary widely with alkalinity source and potentially be significant. See Speece (1996) for treatment options and cost calculations.

iii. Alkalinity should be tested and determined later during full-scale reactor operation in proportion VFA levels, and residual alkalinity calculated.

c. COD/N/P should be approximately 100/4/1 by weight (Bouallagui et al., 2004b). Low N or P levels will ultimately limit digestion, but may take more than 20 to 40 days to manifest in a large scale system.

i. Co-digestion with a nutrient-rich substrate may help. Otherwise, nutrients must be added. E.g. manure and yogurt are high in phosphorus; manure and beans are high in nitrogen.

ii. Estimate the cost of nutrient addition per year. The cost will depend on which compound(s) are chosen as a nutrient source. These costs account for operating costs and are calculated by equations H.5 and H.6.

Cost of N addition ($/yr) = [Required N (kg N/1000 kg COD) *COD loading (kg/day) - Available N (mg/L) *1 kg/1000 mg*wastewater loading (L/day)] *cost of N ($/kg as N) * days of operation/yr [H.5]

Cost of P addition ($/yr) = [1/4 *Required N (kg N/1000 kg COD) * COD loading (kg/day) – Available P (mg/L) * 1kg/1000 mg * wastewater loading (L/day)] * cost of P ($/kg as P) * days of operation/yr [H.6]

d. Total solids >10% can inhibit digestion, particularly in batch tests.

e. The % Volatile solids is the organic fraction, which is available for biodegradation.

f. High sulfide concentrations will produce H_2S gas, and sulfate concentrations will promote sulfate reducing bacteria which produce H_2S gas. The biogas may need to be pretreated.

    i. For example, Tennessee air permits required less than 1800 ppm H_2S so an industrial digester installed a biogas scrubber (Rosdil, 2006).

ii. Some internal combustion engines can utilize biogas if the hydrogen sulfide is less than 60 ppm.

iii. Hydrogen sulfide at 800 to 1000 ppm can be fatal to humans.

g. High salt concentrations may inhibit digestion. Over time, a digester may be able to acclimate to a higher degree.

h. High phenol or LCFA concentrations may require pretreatments (see Chapter 2: Literature Review), which would raise capital and/or operating costs, depending on the chosen treatment method.

6. If initial test concentrations are within the acceptable ranges, continue to Section H.5. If some of the concentrations are outside the appropriate ranges, estimate the costs to rectify these issues.

a. If the required nutrient addition or toxicity treatment is economically prohibitive, the waste-stream is inappropriate for anaerobic treatment.

H.5 Anaerobic Respirometry

The respirometer is used to conduct the biodegradability tests (similar to serum bottles). Microbial seed, nutrient media and wastewater substrate are measured out in multiple reaction flasks. Flasks are stirred and incubated at a constant temperature in a water-bath. The respirometer measures individual real-time biogas production for each flask. Computer software calculates progressive gas production rates and cumulative gas production. Gas samples of the headspace are collected by syringe and analyzed by gas chromatograph to determine the percent methane production. The specific procedure is presented below.

1. Collect an appropriate feed stock sample from the processing plant. Synthesized feed solution CANNOT be used. The full array of processing waste constituents cannot be replicated and may include disinfectants or toxic compounds that could disrupt anaerobic digestion, the affects of which must be properly analyzed. Any solid waste in the sample should be removed or processed to a liquid consistency and diluted to a total solids content of 1 to 5%. To test the biodegradability of intact solid constituents consider implementing a bench-scale reactor instead, as high solids content can inhibit batch systems.
2. Identify an anaerobic seed source. Possible resources include a local anaerobic digester, a lagoon at the food processing plant showing evidence of anaerobic activity, manure (rumen) slurry or a lab culture.
    a. To maximize biological activity, collect fresh seed just before setting up the respirometer. Color can serve as an indicator of anaerobe quality. Active seed will exhibit a dark black color; inactive or unviable seed may be grey or light olive green.

b. Refrigerate the seed sample if time necessitates. Anaerobes will remain dormant yet viable at low temperatures. A longer refrigeration period will result in a longer start-up time; in this case such a delay is not the result of toxicity or acclimation but from the anaerobes slow reactivation.

3. Set up the respirometer. See Appendix I for the respirometer set-up procedure and the Challenge System respirometer manual.

4. Collect gas samples from the head space of each reaction flask. Analyze the samples via gas chromatography and record the CH_4 and CO_2 fractions throughout normal reactor operation.

   a. At a minimum, sample the flasks during peak gas production and at the end of the run.

   b. Designate one gas-collection syringe for all sampling to ensure the same operation and sample volume for each flask.

   c. Between samplings flush the syringe with ambient air several times (rather than headspace gas), to minimize the volume drawn from the flasks and reduce negative pressure in the respirometer's bubble counters.

d. Use gas cylinders of standardized composition (CH_4 and CO_2) to establish a calibration curve. Verify calibration with each sampling event.

5. If methane production remains low or unstable 15 days after startup, consider the following amendments.
   a. Add a greater volume of seed to each flask.
   b. Add more micronutrients (S, Fe, Ni, Co)
   c. If solid waste is being tested, be sure to dilute to < 5% TS.
6. End the respirometer test once all flasks cease gas production. Test the pH and COD of each flask.
7. Analyze the respirometer results.
   a. Graph the cumulative biogas production (mL) vs. time (days).
   b. Graph the biogas production rate (mL/hr) vs. time (days).
   c. Calculate the approximate percent theoretical methane production.
      i. Subtract out methane production from the seed control.
      ii. The theoretical (maximum possible) methane production is 395 mL CH_4 per 1000 mg COD at 35°C.
   d. Compare methane potential to current energy usage. Use the results from sections H.2.2 or H.3.1 (COD) and section

H.5.7 (respirometer) to reassess the economic benefit of an anaerobic system (first evaluated in section H.3.5). 1 thm can be provided by 96.7 ft^3 natural gas.

8. If the overall respirometer results are poor (after allowing 30 for seed acclimation), then conduct a toxicity test (section H.6) to determine if substrate components are a source of methanogen inhibition. Poor results are constituted by:
   a. < 60% CH_4 fraction in biogas
   b. < 60% theoretical biogas produced.
9. If respirometer methane production is good, then proceed to Section H.7 to interpret the overall results.

H.6 Toxicity Test

If overall respirometer tests are poor, conduct a toxicity test.

1. See Speece (1996) and/or Owen et al. (1979) for toxicity test methods. The basis of the test is to monitor gas production rate while adding increasing levels of substrate. If the methane production rate decreases as the substrate level added increases, this is an indication of toxicity.
2. If toxicity is confirmed, conclude 'no further study' is necessary and report anaerobic digestion to be an inappropriate treatment technique for this substrate.

3. If toxicity is not an issue, essential nutrients may be lacking or the seed-to-substrate ratio in the reaction flasks may be too large to distinguish gas production from the substrate. Consider a different respirometer set-up and run the test again with fresh seed.

H.7 Interpretation

1. Compare the predicted COD destruction and methane production to the intended treatment goals and biogas applications. Compare methane results to theoretical methane production and energy potential.
2. Consider implications of various results, including economic and environmental consequences.
   a. If nutrients are lacking and respirometer results are poor, co-digestion may be worth considering.
   b. Re-evaluate the protocol for the blended substrate conditions.
3. If conclusions support anaerobic digestion, the processor should then conduct a pilot scale reactor study. Small batch tests such as the respirometer provide are not representative of large-scale mixing effects or sustained alkalinity needs. Pilot scale reactors must be tested before full-scale projects are pursued.

APPENDIX I

RESPIROMETER SET-UP PROCEDURE

I.1 Flask Allocation

Determine the desired flask assignments including which will serve as controls and which as duplicates. Then determine the appropriate volume allocation of substrate, seed (if used) and nutrient solution (if used) for each flask, using the following guidelines. When any constituent is not used for a particular flask, that volume should be replaced with de-ionized water.

First, allocate the substrate. Include between 150 and 250 mg COD. More than 150 mg should insure a significant net biogas volume; less than 250 mg should insure that the trial finishes in less than 45 days, though this will also depend on the seed activity. This COD amount will correspond to a given volume of substrate based on its COD concentration (mg/L). Subtract this substrate volume from the working flask volume, where the working volume is equal to the total volume less 10% for the headspace. This remaining volume consists of the seed and nutrient solution:

$$V_{\text{Seed + Nutrients}} = 0.9\ V_{\text{Total}} - V_{\text{Substrate}} \qquad \text{[G.1]}$$

where $V_{\text{Substrate}} = 200 \text{ mg COD} / X \text{ mg/L COD}_{\text{Substrate}}$

The seed and nutrient volume is subdivided at a ratio of 1 part seed to 4 parts nutrient solution. Resazurin, an oxygen indicating dye, should be added to each flask for a final concentration of 1 mg/L. For 600 mL flask volumes, add approximately 0.5 mg. As resazurin is a fine powder, it is easiest to first mix a concentrated solution (1000 mg/L) dissolving 10 mg in 10 mL of water and then pipetting 0.5 mL into each flask.

Most flasks will not include all three components. For these cases, replace any component (or partial volume, e.g. ½ nutrients or ½ [wastewater, seed, nutrients]) with de-ionized water. This insures the different flasks have comparable dilutions.

I.2 Nutrient and Metal Solutions

The nutrient solution is composed of mineral and metal solutions. This is such because the trace metals are at such a low concentration in the nutrient solution that it is necessary to mix a more concentrated metal solution first. The nutrient solution is taken from Shelton and Tiedje (1984).

Measure out one liter of de-ionized water into an Erlenmeyer flask with a stir bar on a stir plate. Add to the flask the following measured amounts.

- 0.500 g $MnCl_2 \cdot 4H_2O$
- 0.050 g H_3BO_3
- 0.050 g $ZnCl_2$
- 0.030 g $CuCl_2$
- 0.010 g $Na_2MoO_4 \cdot 2H_2O$ [1]
- 0.500 g $CoCl_2 \cdot 6H_2O$
- 0.050 g $NiCl_2 \cdot 6H_2O$
- 0.050 g Na_2SeO_3

[1] In the original text, this is denoted '$Na_2Mo_4 \cdot 2H_2O$', and is assumed to be an error.

This constitutes the metal solution. Only a small fraction will be used for the nutrient solution; the remaining can be stored for later testing.

New mineral solution should be made for each respirometer trial. For the mineral solution, measure out enough de-ionized water to satisfy the flask allocation requirements of nutrient solution, and pour into an Erlenmeyer flask with a stir bar on a stir plate. Add to the flask the following amounts per liter of water.

- 0.270 g KH_2PO_4
- 0.350 g K_2HPO_4
- 0.530 g NH_4Cl
- 0.075 g $CaCl_2 \cdot 2H_2O$
- 0.100 g $MgCl_2 \cdot 6H_2O$ [2]
- 0.020 g $FeCl_2 \cdot 4H_2O$

[2] In the original text, this is denoted '$MgCl \cdot 6H_2O$', and is assumed to be an error.

Once all is dissolved, pipette 1 mL of metal solution into the mineral solution. Transfer this mixed solution into glass jars with autoclavable caps. Measure out the volume of de-ionized water required for the flask allocations into similar glass containers. Sparge the headspace of each container with nitrogen gas for at least ten seconds and cap tightly. Autoclave the containers for ten minutes to drive off any dissolved oxygen. Once the containers have cooled to room temperature (can be the following day), carefully transfer the solution to a large Erlenmeyer flask taking care not to aerate it. Continuously sparge the flask headspace with nitrogen gas while stirring gently with a stir bar and stir plate. Add 1.20 g $NaHCO_3$ per liter of solution, and cover the flask with parafilm.

I.3 Flask Set-up

Remove the wastewater sample(s) from storage to warm up. Collect the seed sample at this time (if possible) and leave it at ambient temperature (or remove from storage and warm to ambient temperature. Add a stir bar to each clean reaction flask and then measure out the flask constituents, doing one at a time for all flasks. Cap the flasks tightly, with a new septum in each cap. Take care not to over tighten the caps and break them.

The color of the resazurin in the flasks should turn from blue to pink as the seed (and sometimes the wastewater) is added, and again from pink to 'colorless' as the flasks are placed in the water bath and stirred. This color change is indicative of reducing conditions and microbial activity.

As soon as possible, fill the water bath and place in the flasks, and then start the water bath heater. It is best to bring up the flask temperatures gradually with the water bath, rather than place the flasks in a pre-heated bath and potentially shock the system. Vent the flasks at this time and hook them up to the respective gas counters. Set up the software program and start data collection immediately. The first eight to twelve hours, the gas pressure will equilibrate as the temperature rises. Thus, the reported gas rates will not be representative of true seed activity or actual gas production during this equilibration period. After this initial start up period, check that the seeded flasks have returned to septic conditions and are no longer tinted pink; any pink flasks at this point may indicate a loose cap.

APPENDIX J

PROCESSING PLANT ASSESSMENT WORKSHEETS

Worksheet 1 of 3

Plant Name: ____________________ Contact Info: ____________________

Assessment Date: ________________ Completed By:____________________

1. Have you taken any measures to reduce water use or waste production?

   _____ Yes ______ No

Please explain: ____

____

2. Have you considered anaerobic digestion?

   _____ Yes ______ No

Please explain: ____

____

3. Anaerobic digestion can potentially produce methane (natural gas). Does the plant use natural gas?

   _________ No

   _________ Yes, approximately ________ thms per month

4. a. What is the current wastewater treatment method? ________________

   b. Are there discharge requirements?

   BOD (mg/L) ___________

   Other ________________

5. Please provide the plant's current process-flow diagram(s).

Please note: All identifying information will be kept in strict confidence.
(Page 1 of 2)

6. Please list in the table below any cleaners, sanitizers or chemical additives used in processing. If certain compounds are only used in specific processing lines (and waste streams) please specify which.

Such compounds may include (but are not limited to):

Oxidizing sanitizers

- Hyperchlorites, chlorine, chloramines
- Organic bromine
- Iodine, alcohol-iodine, iodophors
- Hydrogen peroxide, peroxy acids

Biocides and non-oxidizing sanitizers

- Organic acids (e.g. acetic acid, propionic acid, formic acid, carboxylic acids)
- Acid anionic sanitizers
- Acid-quat sanitizers
- Quaternary ammonium compounds

Chemical Used	**Processing Line/ Waste stream ID**	**Application Frequency (ex: metered in, or weekly)**

Please note: All identifying information will be kept in strict confidence.

(Page 2 of 2)

Worksheet 2 of 3

Plant Name:	Contact Info:
Assessment Date:	Completed by:

Please fill out one worksheet per waste stream, entering as much information as possible

Waste stream Location /ID:		**Avg. Temp:**		**Data from Year ____**
Commodities Processed on this line:				

	Volume (gal/d)	COD (g/L)	BOD (g/L)	pH	T Phos (mg/L)	NH_4 (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Iron (mg/L)	TSS (mg/L)
Jan										
Feb										
Mar										
Apr										
May										
Jun										
Jul										
Aug										
Sep										
Oct										
Nov										
Dec										

Worksheet 3 of 3

Plant Name:	Contact Info:
Assessment Date:	Completed by:

Commodity:	______	______	______	______	______	______	NOTES
Data from Year ______	Avg. Volume Processed (ton/d)	Avg. Volume Processed (ton/d)	Avg. Volume Processed (ton/d)	Avg. Volume Processed (ton/d)	Avg. Volume Processed (ton/d)	Avg. Volume Processed (ton/d)	
Jan							
Feb							
Mar							
Apr							
May							
Jun							
Jul							
Aug							
Sep							
Oct							
Nov							
Dec							

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