Animal Manure and Other Biomass Residue Conversion into Useful Energy via Fluidized Bed Gasification

Sergio Capareda and Amado Maglinao
Biological and Agricultural Engineering Department
Texas A&M University, College Station
Email: scapareda@tamu.edu

ABSTRACT

On-site animal manure conversion into heat and energy could now be made possible with the use of high throughput fluidized bed gasification systems. A gasifier thermally converts relatively dry animal manure or various biomass feed stocks into heat, synthesis gas, or electrical power. The reaction is endothermic and does not require additional input energy except during the initial start up (around 30 min) using either propane or natural gas. Texas A&M University has developed a skid-mounted fluidized, bed gasification system capable of converting animal manure and other biomass into low calorific value (**LCV**) gas and bio-char. The LCV gas can be cleaned and may be used to run gas engines that are coupled with generators for on-site electrical power production. The char could be recycled into farm lands or upgraded into activated carbon. A demonstration unit is now being completed with a throughput capacity of 70 kg/hr (1.8 tons/d). The advantages of skid-mounted, thermal gasification conversion systems are as follows: (a) high volume reduction of animal manure and wastes; (b) co-production of energy, power, and valuable co-products, and (c) easy transportable unit for mobile applications. This research report will present the results from continuous gasification of numerous biomass residues and wastes.

Keywords: fluidized bed gasification, animal manure, synthesis gas, control systems, slagging and fouling.

INTRODUCTION

Current sources of energy are obtained primarily from fossil fuels; however, they are non-renewable and as the demand for energy keeps on rising, their supply will become a problem. Biomass, like fossil fuels, contains high percentages of carbon and hydrogen and can be a good alternative source of energy (LePori and Soltes, 1985). Even though raw biomass has significantly less energy content than petroleum, it has certain advantages compared to fossil fuels as it is renewable and with enormous reserves exist.

Gasification is one of the thermo-chemical processes that can convert biomass into a useful product known as producer gas or synthesis gas (Reed, 1981). Without complete combustion of the fuel, conversion occurs in an oxygen deficient (partial oxidation) at high temperatures. The partial oxidation process of the biomass takes place at temperatures of about 1400 °F and produces primarily combustible gases consisting of carbon monoxide (**CO**), hydrogen (**H_2**) and traces of methane and some other products like tar and dust.

Fluidized bed gasification is one technology that offers several unique and versatile characteristics for biomass gasification. The turbulent, fluidized state of inert particles in the bed creates a near isothermal zone and enables accurate control of reaction temperatures. Thermal energy stored in large mass of inert particles is rapidly transferred to solid fuel at stable temperatures. Violent agitation of solids provides efficient conversion reactions and allows introduction of fuels having wide variations in composition and particle size (LePori and Soltes, 1985). The advantages of skid-mounted thermal gasification conversion systems are as follows:

a) Excellent reduction in volume of converted biomass,
b) Co-production of energy, power and valuable co-products, and
c) Mobile applications are possible.

This study evaluated the operation of the fluidized bed gasifier developed by Texas A&M University at College Station. The paper presents gasification results from various biomass feedstock. This initial evaluation was done by monitoring the temperature and pressure in the gasifier during its operation and analyzing the gas produced.

OBJECTIVES OF THE STUDY

The specific objectives of the study were as follows:

a) Evaluate the properties of biomass feed stocks used,
b) Develop the control systems for the different biomass feed stocks to be used, and
c) Evaluate the quality of synthesis gas produced.

MATERIALS AND METHODS

The TAMU Fluidized Bed Gasifier

The gasification system used was developed by Texas A&M University at College Station and was protected under US Patent No. 4848249 (Parnell and LePori, 1988). It is a 1-ft diameter skid-mounted fluidized bed gasifier with a feed rate rating of approximately 2.5 lb/min (150 lb/hr or 1.8 tons/d). The needed instrumentation was installed to enable the automatic measurement of temperature and pressure in the gasifier during operation. Figure 1 shows the schematic of the fluidized bed gasifier used in this study.

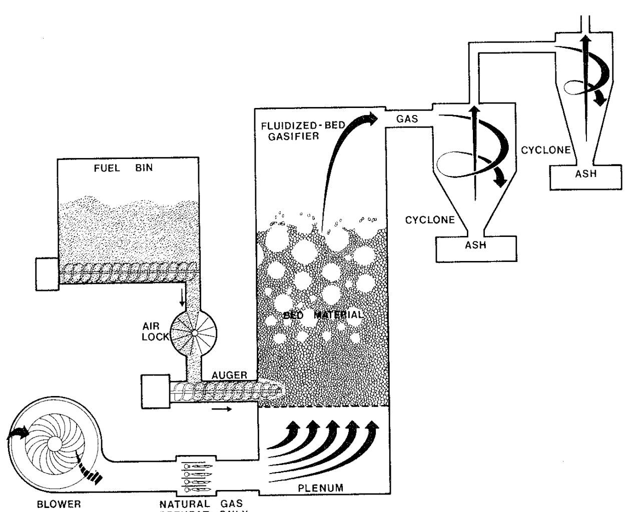

Figure 1. Schematic of the TAMU fluidized bed gasifier.

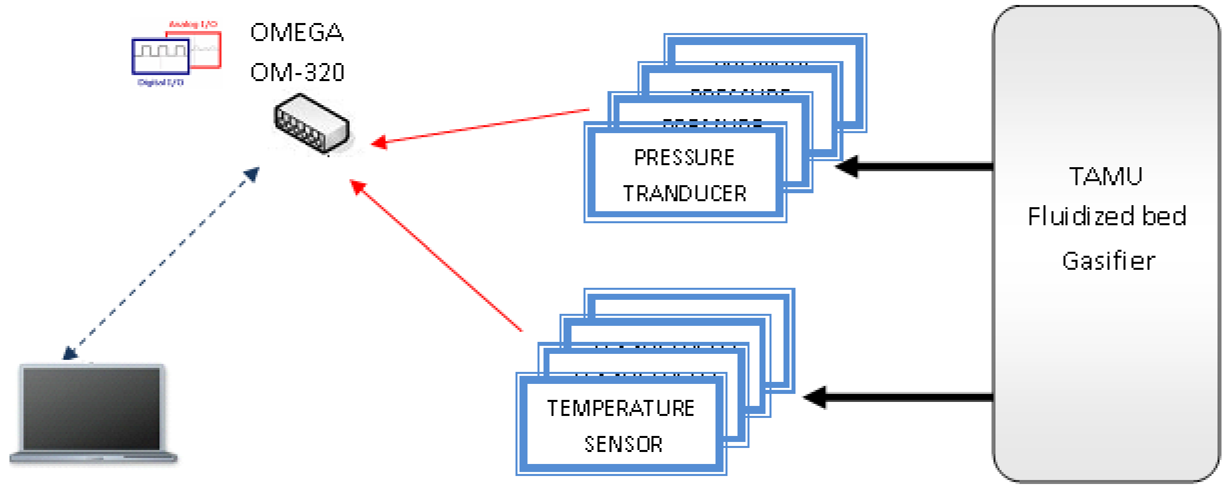

Figure 2. Schematic diagram showing the instrumentation of the gasifier.

Instrumentation and Control System

Figure 2 shows the schematic diagram of how the gasifier was instrumented. K-type thermocouples (Omega CAIN-14U) were installed to measure the temperature at 4 different locations in the gasifier. Differential pressure transducers (Omega PX274 and Dwyer 677) were put in place to determine the pressure inside the gasifier during operation. An Omega OM-320 data logger was likewise connected to continuously monitor the temperature and pressure profiles.

Feedstock Used

Various feed stocks have been tested and these are as follows: wood chips, poultry litter, dairy manure, switch grass, sorghum biomass and cotton gin trash. The biomass stocks, particularly the poultry litter and cotton gin trash, have a high potential as energy sources as they are very abundant. In the state of Texas, approximately 1.5 M dry tons of cotton gin trash and 0.35 M tons of litter have been estimated (Bullock et al., 2008). Moreover, they can provide a net recoverable heat of about 6 M MMBtu/yr and 0.6 M MMBtu/yr, respectively.

Feedstock Characterization

For each feedstock used for gasification tests, the following analyses were made:

a) Heating value,
b) Proximate analysis (moisture, volatile combustible matter, fixed carbon, and ash), and
c) Ultimate analysis (carbon, hydrogen, oxygen, nitrogen, and sulfur contents).

The ash, fixed carbon (**FC**) and volatile combustible matter (**VCM**) contents were analyzed using a thermogravimetric method according to ASTM standards (E 1755 and E 3175). On the other hand, the heating value was measured from the combustion of the biomass using an oxygen bomb calorimeter (Model 6200 Parr Instruments, IL). High-heating value (**HHV**) is a measure of biomass energy per mass or volume of manure resulting from combustion of biomass using a calorimeter (Mukhtar and Capareda, 2006). The proximate analysis gives a good initial indicator of biomass quality, while a HHV provides a measure of biomass energy per mass or volume of manure. In addition, HHV and proximate analyses were made on char collected from the 1st and 2nd cyclone.

Operation of the Gasifier

Calibration studies were made for each feedstock used in the study and the calibration constants are encoded in the Labview Program (National Instruments, Austin, TX). The program controls the mechanically driven auger feed system. To double check the feed rate used during each operation, 5 gal buckets full of dried biomass feedstock were pre-weighed and fed into the hopper system at regular intervals or at a rate of approximately 2.5 lb/min. The refractory bed material in the gasifier was fluidized and preheated (around 30 min) using an air compressor and natural gas burner. When operating temperature is achieved, the biomass feedstock are slowly fed into the system, the pre-heater is turned off until the operating temperature is attained. The pressures and temperatures were measured at different locations within the system and encoded. The inlet pressure drop across the laminar flow element (Meriam LFE 50MC2-2) is being measured and controlled to set the volumetric flow rate through the system. The operating temperature is normally set at around 1400 °F.

Low calorific value (**LCV**) gas samples were taken after the 2nd cyclone. A gas analyzer (DeJaye Technologies, LLC, Des Moines, IA) and another online gas analyzer (HORIBA Scientific, Irvine, CA) were installed and used to measure the composition of the synthesis gas during the operation. Further analysis of the gas composition was done using a gas chromatograph (SRI Model 810C, Torrance CA). The char collected at the 1st and 2nd cyclones were also measured after each run.

RESULTS AND DISCUSSIONS

Biomass Properties

Table 1 shows the HHV and proximate analysis from various feed stocks tested using the TAMU fluidized bed gasifier. The proximate analysis showed that woodchips had the highest content of FC and VCM while generating the lowest ash residue. Cotton gin trash had the second highest values of FC and VCM while poultry litter had the lowest. However, poultry litter had the highest ash content, followed by the cotton gin trash. In terms of HHV, woodchips also exhibited the highest, followed by cotton gin trash, then by poultry litter. This indicates that approximately 18,000 MJ of biomass energy can be produced from 1 metric ton of woodchips, with only 18 kg of ash generated. These data somehow indicate that woodchips would be a better feedstock in terms of proximate analysis and HHV. Table 2 shows the ultimate analysis of some feed stocks used.

Table 1. Proximate analysis and high heating value (HHV) of the feedstock used.

Biomass	Proximate Analysis % Ash (db)	% VCM (db)	% FC (db)	HHV (db) MJ/kg
Poultry litter	39.74 ± 0.98	55.20 ± 2.15	5.06 ± 1.48	10.2391 ± 0.6797
Woodchips	1.80 ± 0.89	85.44 ± 0.19	12.76 ± 0.58	17.8588 ± 0.5839
Cotton gin trash	12.87 ± 0.46	76.94 ± 0.80	10.18 ± 0.57	13.5159 ± 0.7775

[1]db = dry basis

Table 2. Ultimate analysis values of some of the feedstock used.

Biomass	Carbon %	Hydrogen %	Oxygen %	Nitrogen %	Sulfur %	Ash %
Dairy Manure	47.79+0.43	5.54+0.14	36.87+1.38	1.71+0.30	0.36+0.03	7.73+1.05
Woodchips	46.75	6.21	46.13	0.10	0.02	0.79

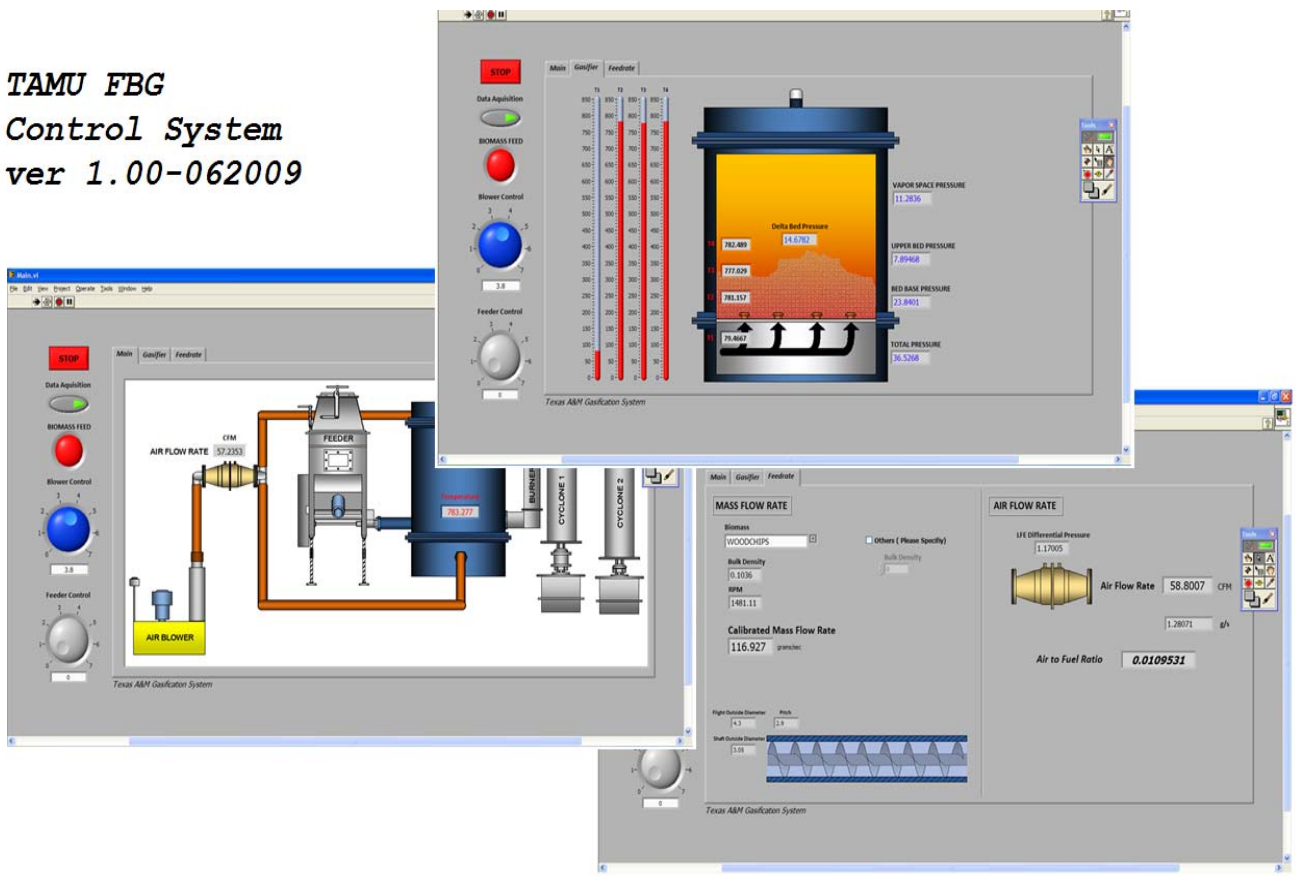

Figure 3. The TAMU gasification control system.

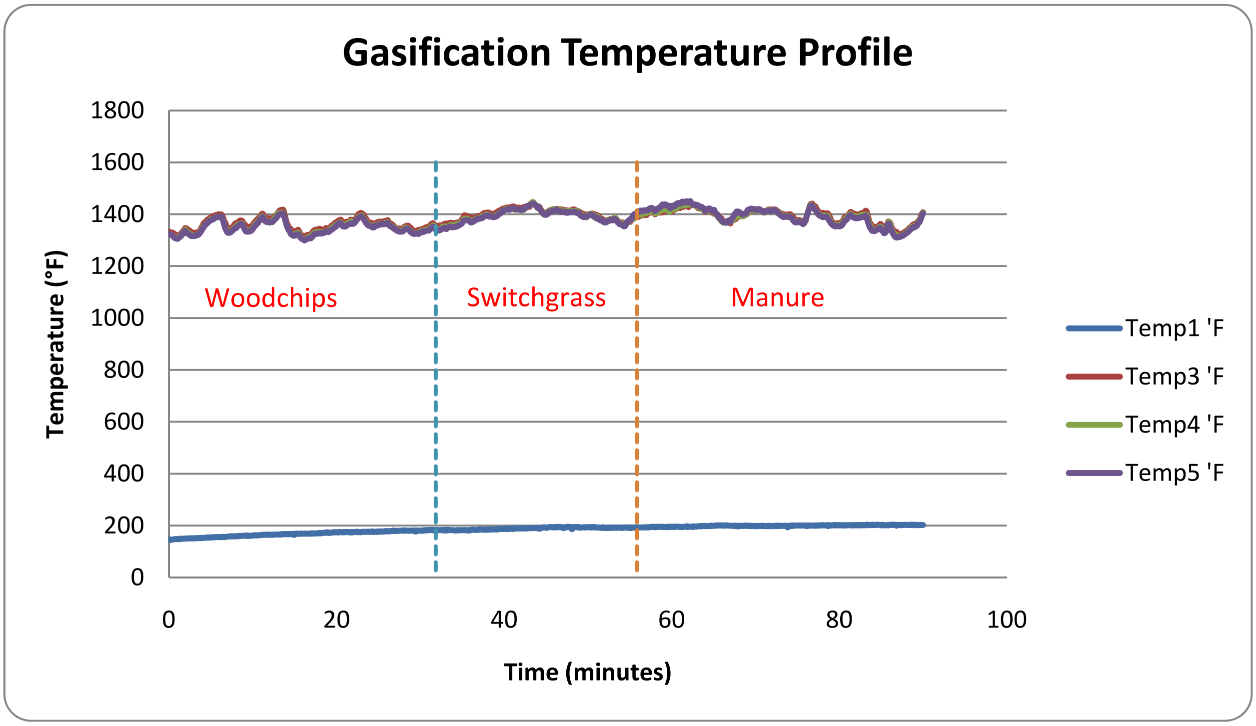

Figure 4. Temperature profile in the gasifier using various feed stocks.

Control System Development

A new control system was designed (Maglinao et al., 2008) and integrated in the TAMU pilot fluidized bed gasifier (Figure 3). The programmable control system allows the gasifier to be monitored and controlled using a simulation program on a computer. During the tests, temperature and pressure profile were obtained while the air and feedstock flow rate were controlled using a LabVIEW program (National Instruments, Austin, TX). The temperature profile during a typical run for various feed stocks is shown in Figure 4.

The temperature profile in the reactor was maintained at approximately 1400 °F even as feed stocks are changed without shutting down the system. This indicates that the turbulent, fluidized state of inert particles in the bed creates a near isothermal zone enabling an accurate control of reaction temperatures. The thermal energy stored in large mass of inert particles is rapidly transferred to solid fuel at stable temperatures.

Composition of the Product Gas

Figure 5 shows the average composition of the gaseous product using poultry litter as feedstock that was performed on a separate test. A relatively higher percentage of N was measured while there was only a trace of ethane detected. The N concentration has an average value of 70.02 % while there was only 0.15 % ethane. Hydrogen has an average of 1.92 % and methane has an average of 3.97%. Other gases determined were oxygen at 6.83 %, carbon dioxide at 9.09 %, and 8.01 % of carbon monoxide and other undetermined gases. The HHV of the synthesis gas was on the average about 115 BTU/ft^3.

Figure 6 shows the synthesis gas analysis using wood chips. Similar to the poultry litter, a relatively higher percentage of N was measured, while there was only a trace of ethane detected. The N concentration has an average value of 65.29 %, while there was only 0.35 % ethane. Hydrogen has an average concentration of 2.20 %, while methane has an average of 2.36 %. Other gases measured were oxygen at 16.70 %, carbon dioxide at 7.11 %, and 5.99 % of carbon monoxide and other undetermined gases.

As observed, synthesis gas produced using poultry litter and woodchips did not generate the expected value of for hydrogen, which should be around 4 – 8 %. This was due to an observed leak in the gas sampling port. Synthesis gas data shown in Table 3 provided a much better concentration value following improved sampling techniques. The HHV of the synthesis gas improved to 150 BTU/ft^3.

This gas is combustible and may be cleaned and used to run internal combustion engines that are coupled with generators. Initial estimates showed that a 1-ft fluidized bed could generate around 200 kW of electrical power. Bigger systems are possible on skid systems up to 1-3 MW. For example, a 1MW unit may be designed with a diameter of 8 ft and if cotton gin trash is used, a feed rate of around 3,300 lb/hr may be necessary. The estimated cost of the unit may be approximately $1M/MW (Maglinao et al., 2008). In the future the same unit may be used for liquid fuel production (Capareda and Parnell, 2007).

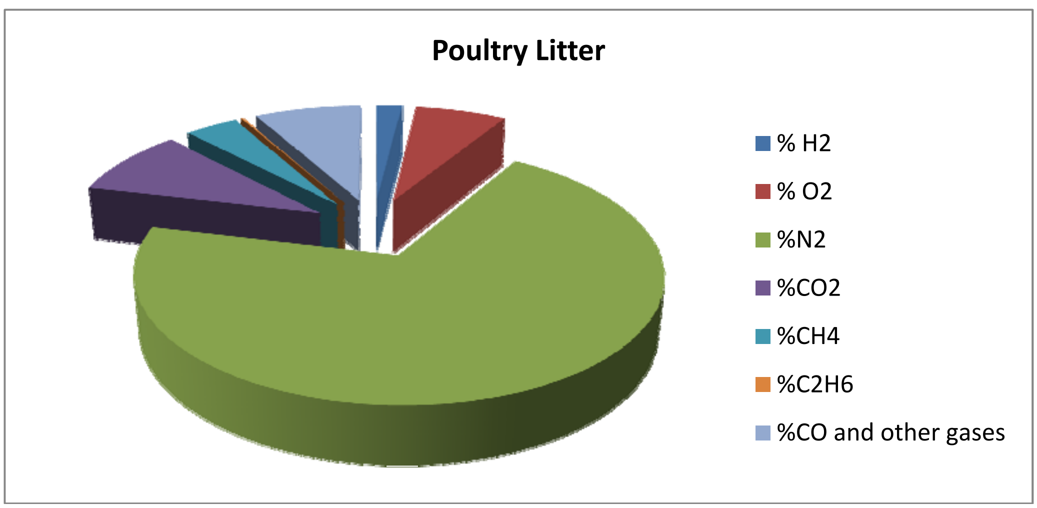

Figure 5. Product gas composition using poultry litter as feedstock

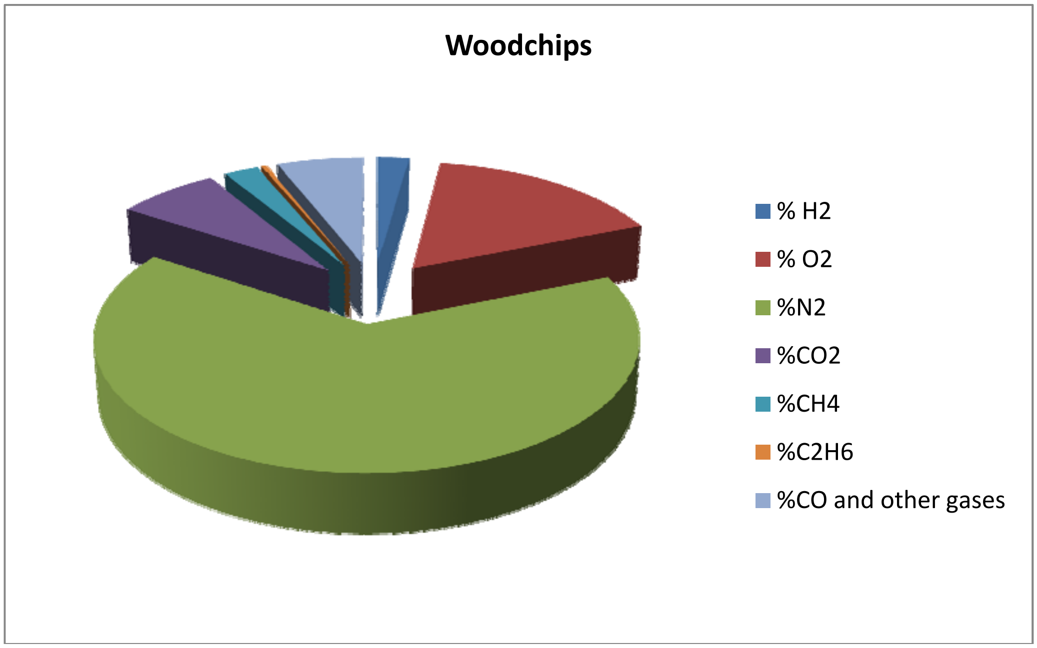

Figure 6. Product gas composition using woodchips

Table 3. Synthesis gas concentration

Synthesis Gas	Concentration
Hydrogen	**17.82+0.27%**
Methane	**7.90+0.02%**
Carbon Monoxide	**27.13+0.06%**
Nitrogen	**30.42+0.12%**
Others	**16.72+0.06%**

CONCLUSIONS

The fluidized bed gasifier developed at Texas A&M University, College Station was tested using various biomass feed stocks. A new computer control system has been developed to monitor and control parameters such as operating temperature and feed rates. The composition of the synthesis gas produced was analyzed and found to have an energy content of around 150 Btu/ft^3. The control system was able to maintain the operating temperature at around 1400 °F (760 °C) using various feed stocks such as woodchips, switch grass, and animal manure. After a start up time of approximately 30 min, a near isothermal zone and a good control of reaction temperatures were obtained.

The initial synthesis gas produced did not generate the expected value for hydrogen at first due to a leak in the sampling port, which should be around 4 – 8 %. Improved sampling brings the hydrogen percentage to near 18 % and methane to 8 %, improving the heating value of the gaseous products. This study showed that the TAMU fluidized bed gasifier is able to convert various biomass feed stock into combustible synthesis gas. The synthesis gas may be used to generate heat or electrical power. Portable systems are possible and may provide on-site production of heat or electricity that may be used by a facility or electrical power that may be sold to the grid.

ACKNOWLEDGEMENT

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