EXPERIENCE WITH ATMOSPHERIC FLUIDIZED BED GASIFICATION OF SWITCHGRASS

Jerod Smeenk and Robert C. Brown

Center for Coal and the Environment
Iowa State University
286 Metals Development Building
Ames, IA 50011 USA

ABSTRACT

Switchgrass was gasified in a bubbling fluidized bed reactor rated at 800 kW (2.75 MMBtu/hr) thermal input and operating at atmospheric pressure. A combustible gas with higher heating value varying between 4.2 – 5.9 MJ/Nm^3 (114-160 Btu/scf) was produced. Carbon conversion was approximately 85%. Difficulties in feeding high moisture switchgrass inhibited smooth reactor operation. Several feed systems for switchgrass were tried with varying degrees of success. The results of gasification trials using switchgrass as fuel are described.

Keywords: switchgrass, gasification, fluidized bed reactor

INTRODUCTION

The Chariton Valley Biomass Power Project, sponsored by the U.S. DOE Biomass Power Program, has the goal of converting switchgrass grown on marginal farmland in southern Iowa into electric power. Two energy conversion options are under evaluation: co-firing switchgrass with coal in an existing utility boiler and gasification of switchgrass to yield product gas suitable for operation of a molten carbonate fuel cell. Iowa State University is conducting gasification tests on switchgrass and Energy Research Corporation is analyzing theoretical performance of carbonate fuel cells operated on the product gas. This paper provides details on the gasification tests.

The gasifier is an air blown, fluidized bed reactor operating at atmospheric pressure. This pilot-scale gasifier is designed to convert up to 4.5 tonnes (5 tons) per day of switchgrass. A description of handling, preparation, and feeding of switchgrass in the pilot-scale facility is provided in this paper. The gasifier is instrumented to obtain information needed to support integration of a carbonate fuel cell with the gasifier. A description of this equipment is also included. Switchgrass composition as well as gas composition and heating value were determined as part of this study.

RESEARCH EQUIPMENT AND METHODS

Gasification trials were conducted at the Biofuels Facility on the ISU campus which houses a pilot-scale fluidized bed reactor, illustrated in Fig. 1, suitable for combustion, gasification, and pyrolytic gasification studies. The system is designed to process about 180 kg/hr (400 lb/hr) of solid biomass fuel, which corresponds to approximately 800 kW (2.75 MMBtu/hr) thermal input at a fuel heating value of 2.3 kJ/kg (7000 BTU/lb). For discussion purposes, the system will be broken down into its major components: the fluidized bed reactor, the data acquisition system, the gas analysis system, and the feed system.

Fluidized Bed Reactor

Biomass fuels are processed in an atmospheric bubbling fluidized bed reactor. Because fluidized beds can handle a variety of feedstocks, they are well suited for this application. The reactor is 46 cm (18 inches) in diameter and measures 2.44 m (8 feet) tall. The reactor is split into two sections: a bed section and a freeboard section. Both sections are constructed of mild steel. Numerous access ports that allow for temperature and pressure monitoring, fuel delivery, and ignition penetrate the reaction vessel. The freeboard section has a view port. Both sections of the reactor are lined with a one-inch-thick refractory liner that protects the steel and insulates against heat loss.

The bed is fluidized with either air provided by a regenerative blower or house steam from the university physical plant. The air flow rate during gasification is 2.85 Nm^3/min (100 scfm) corresponding to a superficial velocity of 0.95 m/s (3.1 ft/s) at a bed temperature of 700 ° C (1300 ° F). Purge air is also supplied at the head of the injection auger to prevent backflow of process gases. The primary fluidization gas enters the bottom of the reactor in the plenum and then flows through a drilled-hole distributor plate. The distributor plate consists of 225 one-eighth-inch holes spaced at one-inch intervals. The fluidization media consists of silica sand and limestone. A nominal bed depth of 60 cm (24 inches) is used. The limestone helps prevent bed agglomeration and reduce tar emissions.

The bed is heated to normal operating temperatures by natural gas combustion in the reactor. A pilot light ignites the air/gas mixture in the reactor. After the reactor is heated to reaction temperatures, solid fuel can be processed. The particulate-laden exhaust stream exits the reactor through the freeboard and passes through a series of cyclones. The cyclones are designed to remove 50% of particles 7.5 m m in diameter or larger. Upon leaving the final cyclone, the combustible gas is ignited by a spark electrode in a diffusion flare.

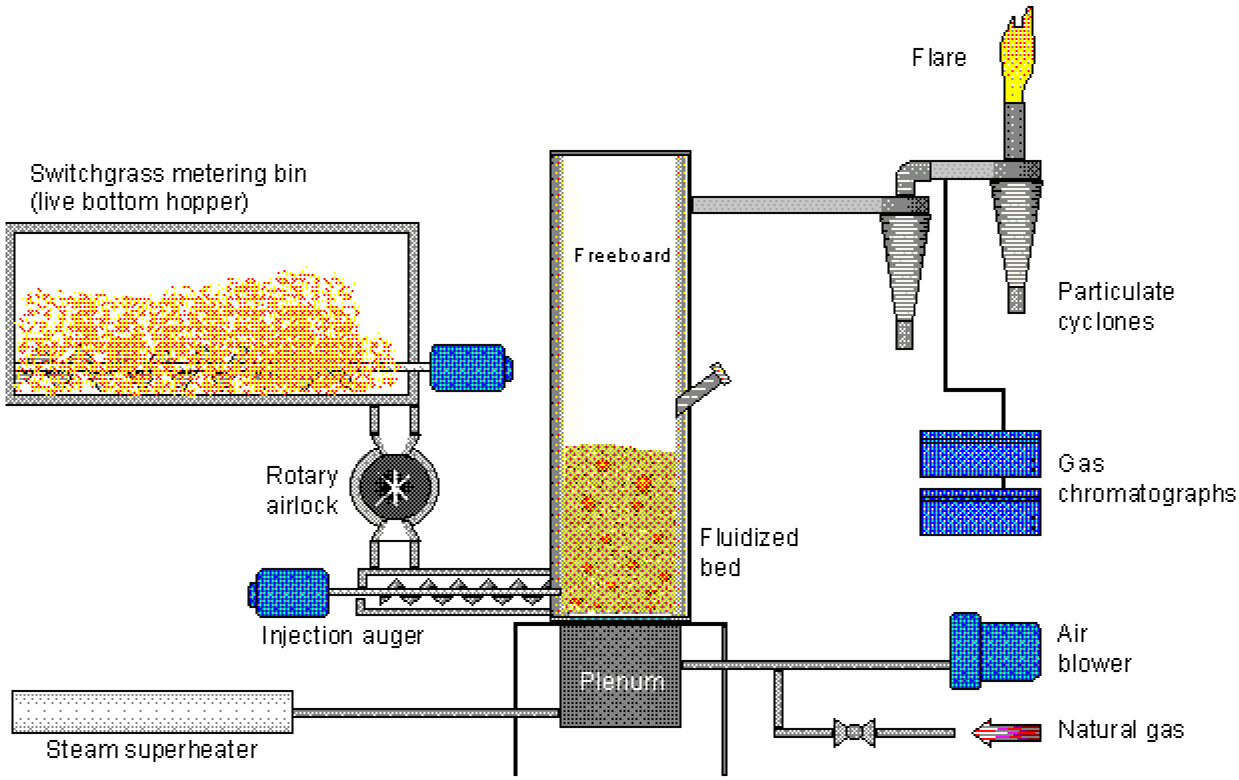
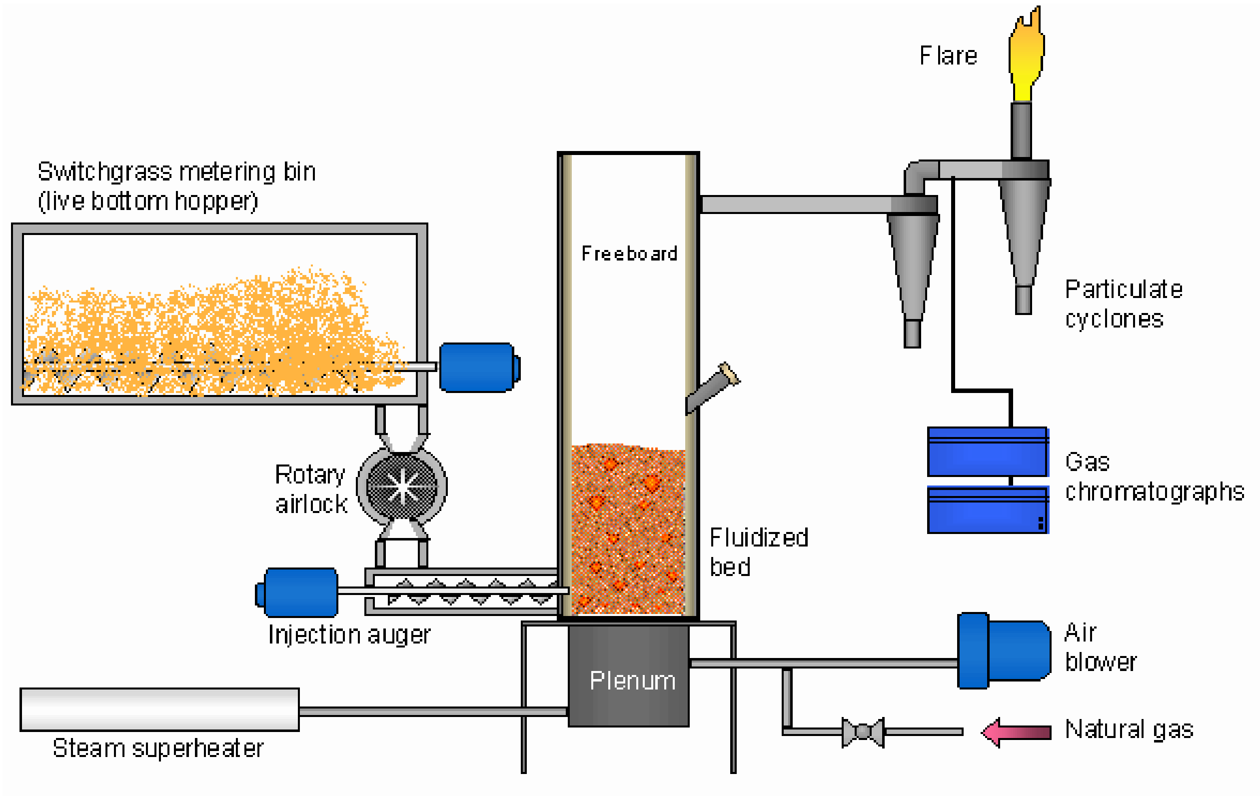


Figure 1. Schematic of the Fluidized Bed Gasifier and Switchgrass Feed System.



Data Acquisition and Control System

Several important process variables are monitored and controlled during gasification trials. An IBM PC compatible computer equipped with a National Instruments data acquisition system manages the process. LabVIEW software was used to program the system. Thermocouples monitor the bed temperature, flue gas temperatures, and other system temperatures. Pressure taps along the side of the reactor allow the fluidization conditions of the bed to be monitored. Pressure differential and fluctuations in the fluidized bed can be used as diagnostic tools. The program also controls variable speed drives hooked to the blower and metering auger, a steam flow control valve, and the pilot light safety control loop. In addition to monitoring and control, the system also records data at specified time intervals.

-

Gas Analysis System

Producer gas composition is determined by gas chromatography and a Fourier transform infrared (FTIR) spectroscopy. Tar, moisture, and particulates are removed from the flow before the gas passes through these analytical instruments. Tar and moisture content are determined by extractive sampling through a cold trap.

Material Preparation and Feeding

The conundrum of switchgrass, as well as many other types of fuel, is feeding the material into the reactor. The fluidized bed reactor operates with forced-draft air, which results in a slight positive pressure at the bottom of the bed where the fuel is injected. The pressure at the injection point is typically 40-50 inches of water column. Although this pressure is relatively small, it is large enough to induce a strong backflow of hot gases through the feed system.

Several methods of handling and injection were tried to overcome this problem. Injection augers operating at different speeds, various types of airlocks, and a plug at the inlet of the reactor were all tested, but none completely eliminated the backflow of hot gases. Figure 2 is a schematic of the plug maker feed system. Initial trials revealed an insufficiently tight plug to prevent producer gas backflow. Tightening the plug resulted in high power requirements. Although this method showed promise, this approach was ultimately abandoned in favor of a standard auger operating with finely chopped switchgrass.

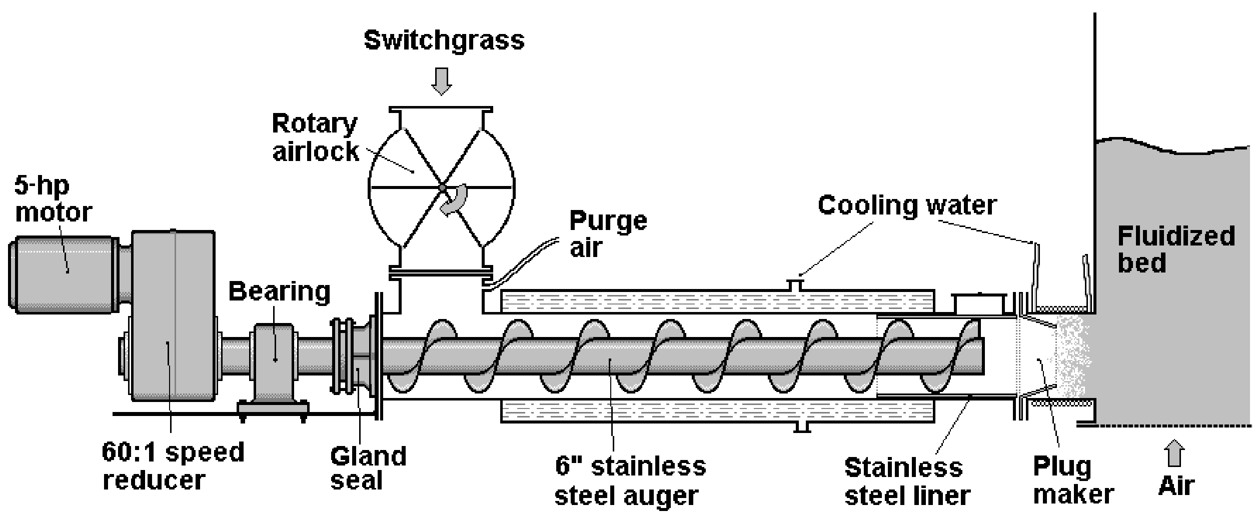


Figure 2. Schematic of Plug Maker for Switchgrass Injection.

Careful attention to feedstock preparation is essential to successful feeding of fibrous materials. The original approach employed minimal preparation. This involved shredding the switchgrass bales in a tub grinder. The result was varying lengths of switchgrass from less than 0.5 cm to as long as 20 cm. Ultimately this resulted in difficult to feed material that bunched easily and hung up in the system, especially when processing switchgrass of high moisture content. A more successful approach processed the switchgrass with a hammer mill. The hammer mill available for this research is mounted in a farm-scale portable mixer-grinder. A 2.5 cm (one-inch) screen resulted in 95% of the switchgrass having a length less than 2.5 cm. The resulting bulk density of the product was 96-128 kg/m^3 (6-8 lb/ft^3).

The switchgrass available for this research was bailed in the late summer of 1996. At that time the moisture content was ~24%. Hay bales do not store well at such high moisture content. In many cases the bales had a wet inner core with some of the grass slightly fermented. Mold was very evident in the bales as they were being processed. Even though the bales were covered, long-term outdoor storage resulted in an average moisture content of 30-35%. Proximate and ultimate analyses of this switchgrass is given in

Table 1.

Table 1. Proximate and Ultimate Analyses of Switchgrass (Dry Basis).

Proximate	Moisture	VM	Ash	Fixed Carbon
	0.0	79.7	5.3	15.0

Ultimate	Carbon	Hydrogen	Nitrogen	Oxygen	Sulfur	Ash
	46.8	5.1	0.6	42.1	0.1	5.3

The material handling system used in the tests discussed below consists of a metering hopper, a rotary airlock, an injection screw, and an exhaust fan. Previous efforts for feeding switchgrass had been total elimination of producer gas backflow. However, to facilitate switchgrass gasification testing, that constraint has been abandoned by using an exhaust fan to collect producer gas which flows back through the system. Figure 3 is a schematic of the metering hopper. The metering hopper measures 1.82 m (six feet) in length with 0.61 m (two feet) side walls. Three of the walls are vertical while the fourth wall is slightly angled to ease loading of the feeder. Two, 22.9 cm (9 inch) diameter counter rotating screws feed material at a variable rate into a rotary air-lock. The hopper works reasonably well but requires almost constant supervision to ensure a uniform feed. Experience suggests that smaller diameter screws would provide better performance for the hopper.

The airlock is constructed of steel vanes with rubber wiping strips. The injection auger is stainless steel and currently rotates at 30 rpm. Rotational speeds greater than 100 rpm are recommended to minimize fuel residence time in the auger. However, this injection auger is the same auger used in the plug injection system which required a slower auger speed. To date, a new high-speed drive system has not been acquired. A new high speed drive would facilitate fuel injection and minimize fuel reactions in the injection auger. Because the fuel does begin reacting in the injection auger, an exhaust fan serves to collect the smoke and other gases which leak back through the system. A large quantity of make-up air is injected below the airlock to minimize the amount of producer gas flowing back through the system.

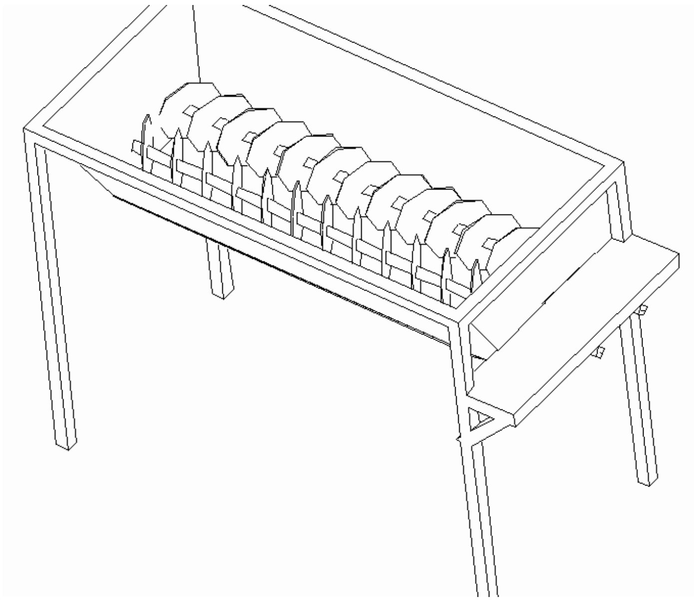


Figure 3. Schematic of live-bottom feed hopper.

RESULTS AND DISCUSSION

Producer gas composition from one of the switchgrass gasification tests is shown in Table 2. Tar and moisture content data were not taken during this test. Approximately 550 kg (1200 lb) of switchgrass were prepared for this test. The reactor was operated with an air injection rate of ~ 3.12 Nm^3/min (110 scfm). Approximately 205 kg/hr (450 lb/hr) of fuel was injected to achieve an equivalence ratio of 0.28. The high moisture content of the fuel resulted in non-uniform feeding of the switchgrass into the reactor. Therefore, slugs of material would be injected in a short time period resulting in a large gas production. This uneven gasification resulted in varying gas composition and high char carry over from the bed.

Gas analysis was determined using a gas chromatograph (GC) and a Fourier transform infrared spectrometer (FTIR). The GC is calibrated for nitrogen, hydrogen, carbon monoxide, methane, and carbon dioxide while the FTIR is calibrated for carbon monoxide, methane, carbon dioxide, and ethylene. The FTIR is able to detect acetylene and ethane but it has not yet been calibrated for these gases. It is unable to detect nitrogen, hydrogen, and oxygen because these gases are optically inactive. The gas is reported on a dry, tar-free basis.

The higher heating value of the producer gas varied between 4.2-5.9 MJ/Nm^3 (114-160 Btu/scf) with an average value of 5.2 MJ/Nm^3 (141 Btu/scf). The carbon conversion for this test is estimated to be 85%. This was determined by doing a rough mass balance on the system. Approximately 540 kg (1200 lb) of switchgrass was fed which on a dry basis is about 380 kg (840 lb assuming 30% moisture). Switchgrass is approximately 47% carbon (by ultimate analysis) equating to a carbon input to the system of approximately 180 kg (400 lb).

Table 2. Gas Composition And Heating Value For Switchgrass Gasification Test.

Sample #	N_2	H_2	CO	CH_4	CO_2	C_2H_4	Total	HHV (MJ/Nm^3)	HHV (Btu/scf)
1	56.18	3.68	12.55	3.53	15.33	1.60	92.87	4.2	114
2	60.18	5.61	17.06	5.16	19.71	2.13	109.85	5.9	160
3	61.40	4.75	14.83	4.37	20.30	1.96	107.61	5.2	139
4	54.68	3.93	16.49	4.85	17.36	1.92	99.23	5.4	146
5	53.88	3.25	16.47	4.94	17.52	1.99	98.05	5.4	146
Avg.	57.26	4.24	15.48	4.57	18.04	1.92	101.52	5.2	141

Approximately 68 kg (150 lb) of particulate material was collected in the cyclones. The particulate matter is approximately 40% carbon yielding an approximate carbon conversion efficiency of 85%. The high char carryover from the bed is probably due to the uneven feeding and gas production. In fact, small fibrous particles were visible in the cyclone catch which is clear evidence of inadequate particle residence time. Several measures may be taken to increase char conversion including a uniform fuel feed, decreasing the superficial velocity, and reinjection of elutriated solids.

CONCLUSIONS

Switchgrass was gasified in a fluidized bed reactor at Iowa State University as part of the Chariton Valley Biomass Power project. Fuel preparation and design of the material handling system are two critical factors for fibrous feedstocks such as switchgrass. The fuel should be uniform in size with stalk lengths no longer than 2.5 cm. Live bottom hoppers must be used to meter the material. Reactor pressure and control of producer gas backflow are also important considerations. Gasification of switchgrass resulted in a dry gas higher heating value of 4.2-5.9 MJ/Nm^3 (114-160 Btu/scf). The carbon conversion efficiency was estimated at 85%. Future work includes additional gasification testing with dry switchgrass, further development of the material handling system, and quantification of tar, moisture, and various fuel cell contaminants.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the Iowa Energy Center, the DOE Biomass Power for Rural Development program, and the Institute for Physical Research and Technology at Iowa State University. The authors appreciate the contributions of Jim Pollard, Ryan Pletka, and Josh O'Donnel in performing gasification tests.