CYCLONE PERFORMANCE TESTING FOR SEPARATING BIOCHAR FROM SYNGAS

D.S. Saucier
C.B. Parnell, Jr.
R.O. McGee
S.C. Capareda
Texas A&M University
College Station, TX

Abstract

Cotton gins have a readily available supply of biomass that is a by-product of cotton ginning. A 40 bale per hour (bph) rated gin can accumulate 4,000 to 9,600 tons of cotton gin trash (CGT) every season. CGT has an energy content of 7,000 Btu/lb. Gasification of biomasses such as CGT can offer processing facilities the opportunity to transform their waste biomass into electricity. The gasification of CGT yields 80% synthesis gas (syngas) and 20% biochar. The biochar infused in the syngas should be separated prior to entering an internal combustion engine driving a generator for electricity production. In Texas A&M's Department of Biological and Agricultural Engineering's provisional patent on fluidized bed gasification, a series of 1D2D and 1D3D cyclones were used to capture the biochar from the syngas. A cyclone test stand was designed and constructed to evaluate cyclone capture efficiencies of biochar. A statistical design was used to evaluate cyclone performances for varying biochar feed rates and cyclone inlet velocities. A total of 24 tests for the 1D2D and 36 tests for the 1D3D cyclone were conducted. Average collection efficiency for the 1D2D cyclone was 96.6% and 96.9% for the 1D3D cyclone. An analysis on the cyclone's pressure drop was performed to compare the change in pressure drop from air only passing through the cyclone and when the cyclones are loaded with biochar. The average decrease in pressure drop for the 1D2D cyclone was 54%, and the average decrease in pressure drop for the 1D3D cyclone was 62%.

Introduction

Cotton harvesting methods yield varying amounts of cotton gin trash (CGT). Pickers yield 150 lb/bale, strippers with field cleaners yield 400 lb/bale, and strippers without a field cleaner yield 800 lb/bale of CGT. A simulation of a 40 bale per hour (bph) rated cotton gin results in the gin's capability of producing 9,600 tons of CGT annually. Cotton gin trash has historically been sold as a roughage for livestock feed or producers spread CGT across their fields as a soil enhancement.

In contrast to fluidized bed combustion, fluidized bed gasification (FBG) is a thermo-chemical reaction in an oxygen-deprived environment. There is insufficient oxygen for combustion in a FBG. The products of a FBG are a low Btu gas and char. The biomass is converted into synthesis gas (syngas). CGT has an approximate energy content of 7,000 BTU/lb. Gasification of CGT yields 80% syngas with an approximate energy content of 150 to 200 Btu/dry standard cubic foot (dscf) and 20% biochar (Capareda et al., 2010). Syngas is used to fuel a modified internal combustion engine to power a generator set (genset) for electricity production. FBG research began in the Department of Biological and Agricultural Engineering at Texas A&M University in the 1980s. The first patent was awarded in 1989 (Lepori and Parnell) and improvements made resulting in a provisional patent in 2010 (Capareda et al.). The improved design of the gasification unit produced gas with increased energy content. A syngas fueled genset and fluidized bed gasification plant has an estimated capital cost of $1 million per Megawatt (MW) as opposed to $2 million per MW for a boiler and steam turbine (Capareda et al., 2010). Cotton gins possess a unique opportunity for utilization of gasification technology as they have a readily available supply of biomass produced from cotton ginning.

Biochar produced from the gasification of CGT must be removed from the syngas before entering a genset. The biochar laden syngas exits the gasifier at an approximate temperature of 1,400ºF. Syngas is flammable and exposure to oxygen could result in an explosion. The ideal method used for the removal of biochar from syngas is cyclones. Airstreams infused with particulate matter (PM) enter the cyclone tangentially creating a vortex. Centrifugal force causes the particles in the airstream to collide with the side of the cyclone and they fall to the bottom of the cyclone. Clean gas exits the top of the cyclone through a smaller vortex in the center of the cyclone. The syngas is not exposed to oxygen while passing through the cyclones. Cyclones are constructed of steel capable of withstanding high temperatures.

In the 2010 provisional patent, the gasifier was designed with a gas clean up system that consisted of a 1D2D and 1D3D cyclone in a series connection. The 1D5D cyclone was removed due to the substantial pressure drops encountered during operation. Increased pressure drops require a fan with more horsepower to fluidize the gasifier bed and convey the biochar laden syngas through the cyclones. The 1D2D and 1D3D cyclones in a series connection have a lower pressure drop than the 1D3D and 1D5D in a series connection.

Materials and Methods

Particulate matter (PM) abatement systems are dependent on the particle size distribution (PSD) and the mass median diameter (MMD) of the particles. A PSD was performed on the biochar through the use of a Coulter Counter. A sample of the biochar was sieved of particles greater than 100 micro-meters (microns) prior to running the sample through the Coulter Counter. Figure 1 is a graph comparing the observed distribution and the theoretical distribution. Typically, PSDs are best defined by a lognormal distribution. The observed versus the theoretical distribution ensures that the PSD of the biochar is of lognormal distribution.

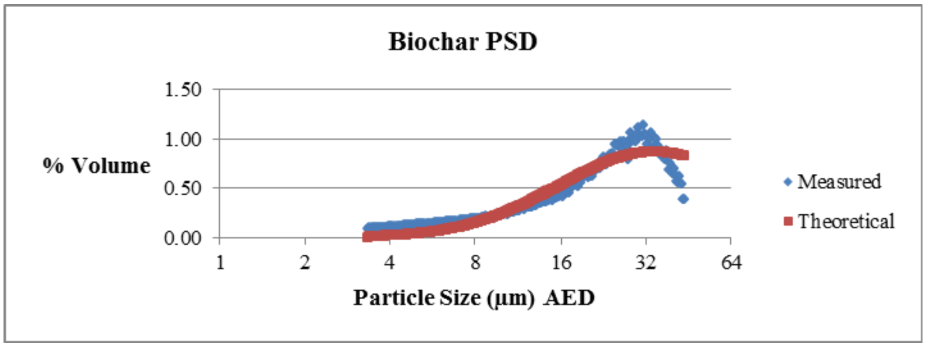

Figure 1. The particle size distribution of the biochar particles. The observed distribution was compared to a theoretical lognormal distribution to ensure that the PSD is of lognormal distribution. The Coulter Counter reveals that the MMD (AED) is 34 microns with a GSD of 2.2.

A cyclone testing system was designed and constructed to evaluate cyclone efficiencies and pressure drops (performance) for anticipated operating conditions. Figure 2 is the cyclone test system. Air and biochar were conveyed through the cyclone with the use of a computer controlled positive displacement compressor. A laminar flow element (LFE) was used to measure pressure and flow rate during each test. The LFE's output was programed into the computer program and adjusted the power the compressor receives. Pressure drops across the cyclone and LFE were recorded at two second intervals and stored for further analysis. Biochar was fed into the airstream by a variable speed rotary air lock.

Figure 2. Cyclone efficiency testing system. Airflow through the system was achieved by a positive displacement compressor that was controlled by a computer program. Biochar was fed into the airstream by an adjustable rotary air lock. Digital differential pressure gauges were used to sense, record, and store pressures cyclone testing.

The goal of this research was to simulate the conditions that would be encountered with the operation of a TAMU fluidized bed gasification unit. Dr. Sergio Capareda's mobile fluidized bed gasification unit has a cross sectional bed area of 1 $ft.^2$. The mobile gasifier unit has been tested using CGT feed rates of two, three, and four pounds per minute. Twenty percent of the CGT is converted into biochar. These feed rates were used to calculate the three simulated feed rates of biochar: 180, 270, and 360 grams/minute (g/m). Air flow conditions vary upon the design inlet velocities for the TAMU 1D2D and 1D3D cyclones. The 1D2D cyclone had a design inlet velocity of 2400 +/- 400 fpm, while the 1D3D had a design inlet velocity of 3200 +/- 400 fpm. Velocities were converted to volumetric airflow rates (Q) in cubic feet per minute (cfm). The flow rates are calculated by multiplying the inlet area of the cyclone by the velocity.

A randomized complete block experiment with four replicates was designed to evaluate the two main factors and their interaction for both cyclones. The 1D2D testing was limited to two levels for the airflow due to the low conveying velocity encountered at the bottom range of the optimal inlet velocity. The 1D3D contains three levels for the airflow factor. Both cyclones have the three aforementioned levels for biochar feed rate. Each test is replicated four times resulting in 24 tests for the 1D2D and 36 tests for the 1D3D cyclone.

Table 1. Experimental design consists of a general factorial to test for factors that significantly affected cyclone efficiencies. The 1D2D cyclone was tested at two flow rates; the 1D3D cyclone was tested at three flow rates. Both cyclones were tested using three levels of biochar feed rates. These rates were determined using typical feed rates used for the mobile TAMU gasifier unit. Each test was replicated four times.

Cyclone	Factor	Level 1	Level 2	Level 3	Response	Replicates
1D2D	Air Flow (cfm)	75	88	X	Efficiency	4
	Char Feed Rate (g/min)	180	270	360		
1D3D	Air Flow (cfm)	88	100	113	Efficiency	4
	Char Feed Rate (g/min)	180	270	360		

Results

Tests were conducted using the experimental design parameters. Efficiencies were determined by measuring the mass of biochar put into the feeder, conducting the experiment for five minutes, and measuring the amount of mass collected by the cyclone. The difference between the two measurements yielded collection efficiencies. The 24 tests for the 1D2D and 36 tests for the 1D3D cyclone are displayed in Figure 3, ranked in order from lowest to highest efficiency. Table 2 is the initial statistical analysis performed on the data. The range, mean, standard deviation, and 95% confidence intervals were calculated. Mean collection efficiency for the 1D2D cyclone was 96.6 ± 0.31% and 96.9 ± 0.22% for the 1D3D cyclone.

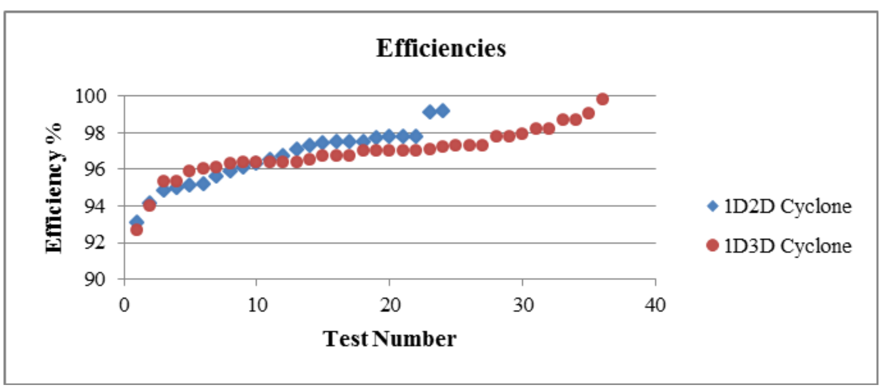

Figure 3. Test results from the 24 tests conducted for the 1D2D and 36 tests for the 1D3D cyclone. The efficiencies were ranked in order from lowest to highest efficiency.

Table 2. Statistical analysis on the data collected from the experiment. The 1D2D cyclone has an average collection efficiency of 96.6 ± 0.31%, while the 1D3D has a slightly higher average of 96.9 ± 0.22%.

Cyclone	Number of Test	Range	Mean	95% C.I.
1D2D	24	93.1-99.2%	96.6 ± 0.31%	95.9, 97.2%
1D3D	36	92.7-99.8%	96.9 ± 0.22%	96.4-97.3%

A statistical analysis was conducted on each individual test and their four replicates to remove outliers for further analysis. Mean, standard deviation, and standard error are calculated for each test. The confidence level was arbitrarily set at 90%. Values that did not fall within the lower and upper bounds of the range are excluded. A total of five tests were removed for the 1D2D cyclone and seven tests removed for the 1D3D cyclone. The mean and standard deviation for the efficiencies for the 1D2D cyclone is 96.9 ± 1.1%, and 97.0 ± 0.96% for the 1D3D cyclone with the outliers removed.

An analysis to determine the effect concentrations of biochar in g/m^3 has on efficiencies with the outliers removed was conducted. A linear regression was performed to calculate the R^2 value for the correlation. The R^2 values for the 1D2D and 1D3D cyclones were 0.17, and 0.25, respectively. The regression results suggest that a relationship may exist between collection efficiencies and concentrations of biochar. Figure 4 is a chart that displays the collection efficiencies vs. concentrations of biochar.

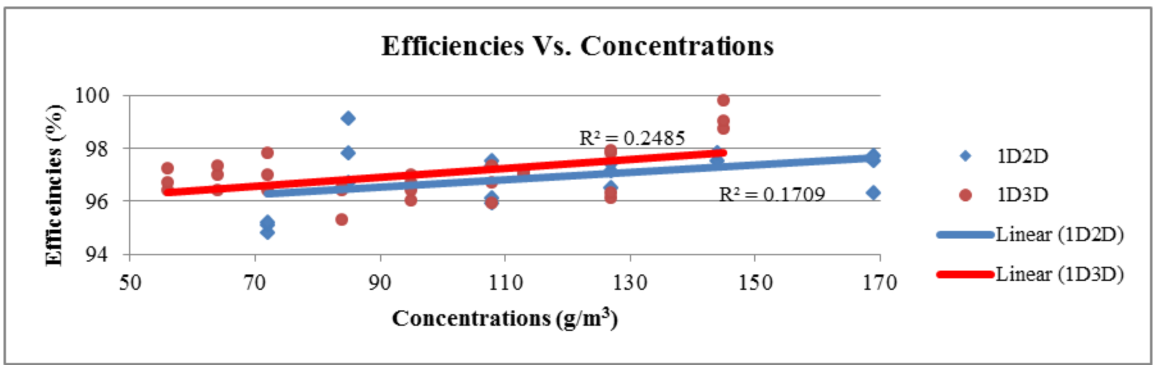

Figure 4. Collection efficiencies vs. concentrations of biochar. A linear regression was performed to determine if collection efficiency is affected by different levels of concentration of biochar.

Pressure drops across the cyclones were recorded at two second intervals during testing. The data were analyzed and averages were calculated for 20 seconds while the cyclones were conveying air only and 20 seconds while the cyclones were loaded with char. The pressure drops between air only and air infused with biochar were significantly different. On average, the pressure drop decreased by 54% for the 1D2D cyclone when loaded with biochar and 62% for the 1D3D cyclone. Figure 5 displays the difference in the pressure drops for the 1D2D cyclone and Figure 6 shows the difference for the 1D3D cyclone.

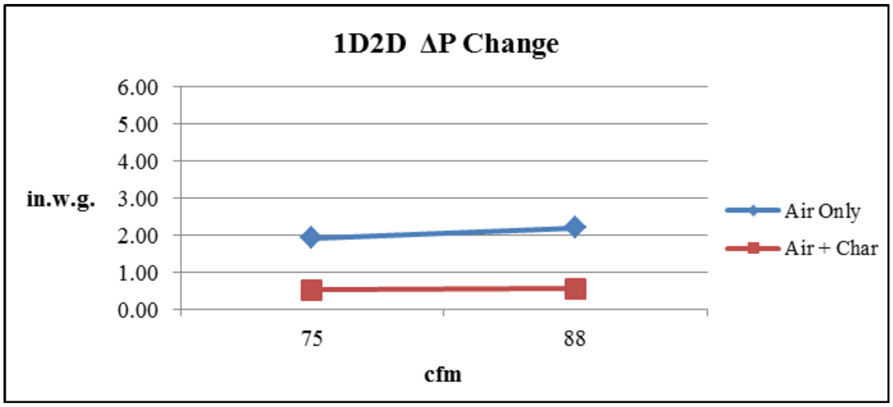

Figure 5. The difference between the average pressure drops across the 1D2D cyclone with air only and when the cyclone is loaded with biochar. The total average pressure drop is a decrease of 54%.

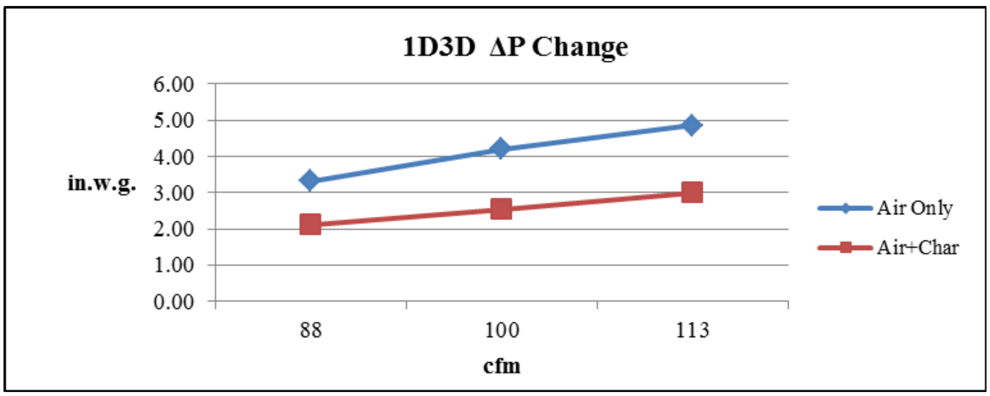

Figure 6. The difference between the average pressure drops across the 1D3D cyclone with air only and when the cyclone is loaded with biochar. The total average pressure drop is a decrease of 62%.

Summary

The biochar's PSD and MMD make it ideal for removal from an airstream with properly designed cyclones. It is vital that the biochar infused syngas is retained in an environment that is sealed with no exposure to oxygen. The high temperatures that are encountered at the exit of the gasifier pose as a potential explosion hazard if oxygen is introduced. Properly designed 1D2D and 1D3D cyclones yielded average biochar collection efficiencies of 96% and higher. Correlation between the cyclone's capture efficiency and concentrations of biochar need further analysis to determine significance. Pressure drops decreased for both cyclones while loaded with biochar. The 1D2D cyclone had an average decrease in pressure of 54% while the 1D3D cyclone's average decrease in pressure was 62%. The decrease in pressure drops would reduce the total pressure that the gasification plant will require.

References

Capareda, S., C. B. Parnell, Jr., W. A. LePori. 2010. Provisional Patent Serial No. 61/302,001.

LePori, W.A. and C.B. Parnell, Jr. 1989. System and Process for conversion of biomass into usable energy. US Patent No. 4848249.