START-UP OF A PILOT-SCALE DOWNDRAFT, IMBERT STYLE GASIFIER USING WILLOW AND SUGAR MAPLE WOOD CHIPS

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Abstract: *The aim of this work was to study the temperature and particle distribution of a small Imbert style downdraft gasifier fueled with shrub willow (salix) and sugar maple (acer saccharum) wood chips during start up. Five different runs were conducted and temperatures were recorded from three levels in the gasifier. Particle sizes were sampled at four levels in the gasifier after each run was completed.*
The smaller wood chips were found to not get up to gasification temperature readily and tended to clog in the gasifier. The larger chips got up to gasification temperature quickly and temperatures were stable during the run. Particle size distribution indicated clogging of the gasifier with the smaller chips as well as the retention of biochar in the gasifier ash pit with both chip types.
It is concluded that the gasifier is able to sustain temperatures and conditions required for all reaction zones of the gasification process if the wood fuel is of the right particle size and moisture content.

Key Words: *Downdraft Iimbert style gasifier, gasification, wood chips, temperature, particle size*

1. INTRODUCTION:

In the United States (U.S.), fossil fuels meet a significant portion of the increasing demand for energy. Of these fossil fuels, coal accounts for 33% of electricity generation in the U.S. [1]. The direct burning of coal for power plants releases carbon dioxide, sulfur dioxide, nitrogen oxides and mercury compounds [2]. As a result, gasification of coal has become more widespread commercially. Gasification is the process in which solid or liquid carbon-rich material react with steam, air or oxygen gases to produce useful gases and chemicals [3]. While the gasification of coal is a step towards cleaner energy production, this process occurs at a much higher temperature than biomass gasification making the process energy-intensive and costly. Biomass research is gaining attention globally due to its abundance and its waste recovery potential [4]. Biomass energy is energy stored in plants and animals and their wastes. Typically, biomass energy is extracted from wood wastes, wood, food processing waste, animal wastes, municipal solid wastes and aquatic plants. Biomass energy is not in ideal form for direct use and requires conversion technologies such as: 1) direct combustion (burning the biomass directly), 2) biochemical (the use of enzymes and yeast - which is costly and time-consuming), or 3) thermochemical which is the fastest, cleanest and most efficient [5].

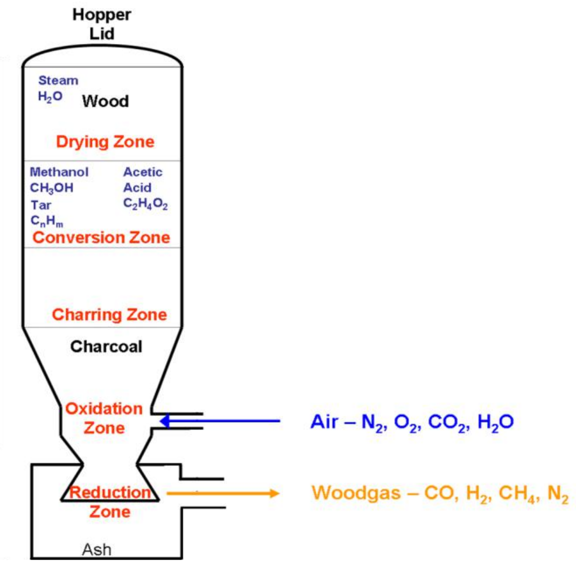

Fig. 1: Imbert Style Gasifier

The thermochemical conversion of biomass includes: pyrolysis, gasification and combustion of the biomass which results in producer gas, a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen gases [6]. Gasification can potentially convert 60-90% of the biomass energy into gas that can then be burnt to produce industrial or residential heat, run engines for mechanical or electrical power, or to produce synthetic fuels [7]. Various designs exist for gasification (most commonly fixed bed, fluidized bed, updraft and downdraft gasifiers). These designs are based upon the input of air flow and the direction of gas output in the system.

The downdraft gasifier has been proven to be the most successful design for small scale power generation due to its low tar production, an inhibiting by-product of the process. Downdraft gasification has not yet been successful for large scale (MW) power production. The downdraft gasifier has four reaction zones: 1) drying, 2) pyrolysis, 3) combustion and 4) reduction. The Imbert design is one in which the gasifier contains a throated combustion zone such that the diameter for the pyrolysis zone decreases into and through the combustion zone and increases again through the reduction zone [4]. Fig. 1 above shows a picture of an Imbert style gasifier. A pilot-scale downdraft, Imbert-type gasifier shown in Fig. 2 below was designed and constructed to be used.

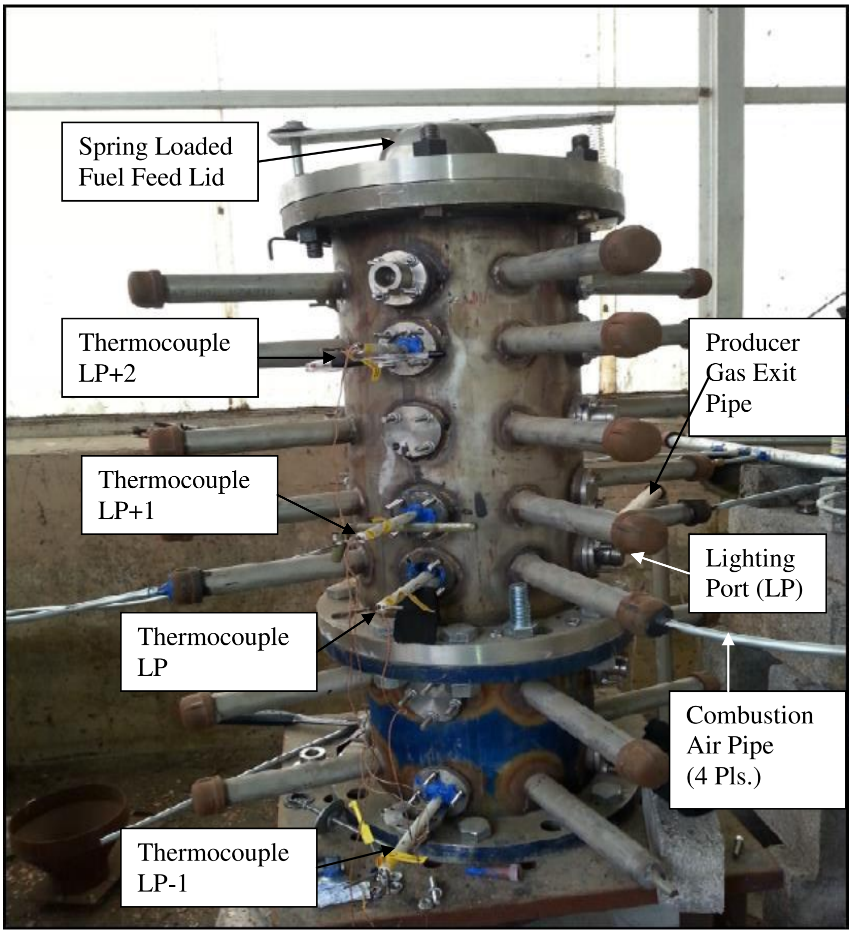

Fig. 2. CERF Gasifier

Cleanwater Educational Research Facility (CERF) located at the municipal Waste Water Treatment Plant (WWTP) in Minoa, NY. Figure 3 below shows a design sketch for the CERF gasifier. The gasifier was designed from 8 inch diameter stainless steel pipe material and included a 1inch thick cylindrical refractory cement layer for the drying and conversion zone of the gasifier. The combustion zone has a conical refractory layer with a 6 inch opening on top and a 2 inch opening on the bottom followed by a mesh plate with 3.75 inch (9.5mm) diameter, followed by a 6 inch diameter carbon steel ash pit. The cast refractory cement lining can withstand temperatures up to 2200°F (1204°F).

This research is a pilot study of the operating conditions of the CERF gasifier. The objectives of this research are to determine the operating temperature distribution in the CERF gasifier as well as the particle size distribution of the gasified material within each region of the gasifier.

Gasifiers are relatively simple devices. The mechanics of their operation, such as feeding and gas cleanup, also are simple. The successful operation of gasifiers, however, is not so simple. No neat rules exist because the thermodynamics of gasifier operation are not well understood. Yet, nontrivial thermodynamic principles dictate the temperature, air supply, and other operating variables of the reactors that we build [7]. Biomass largely consists of hydrocarbons, hydrocarbons combined with the proper amount of oxidizer break down largely into the fuel gases hydrogen, carbon monoxide and methane starting at temperatures above 600°C (1112°F) [7]. Reaction times at this temperature are comparatively slow and the breakdown of hydrocarbons at lower temperatures tends to produce larger amounts of tar. For these reasons gasifiers are generally operated such that the temperatures in the combustion and reduction zone are 700°C (1292°F) to 1000°C (1832°F) [7]. Operation at temperatures above 1000 °C requires that the gasifier be built from more expensive heat resistant materials.

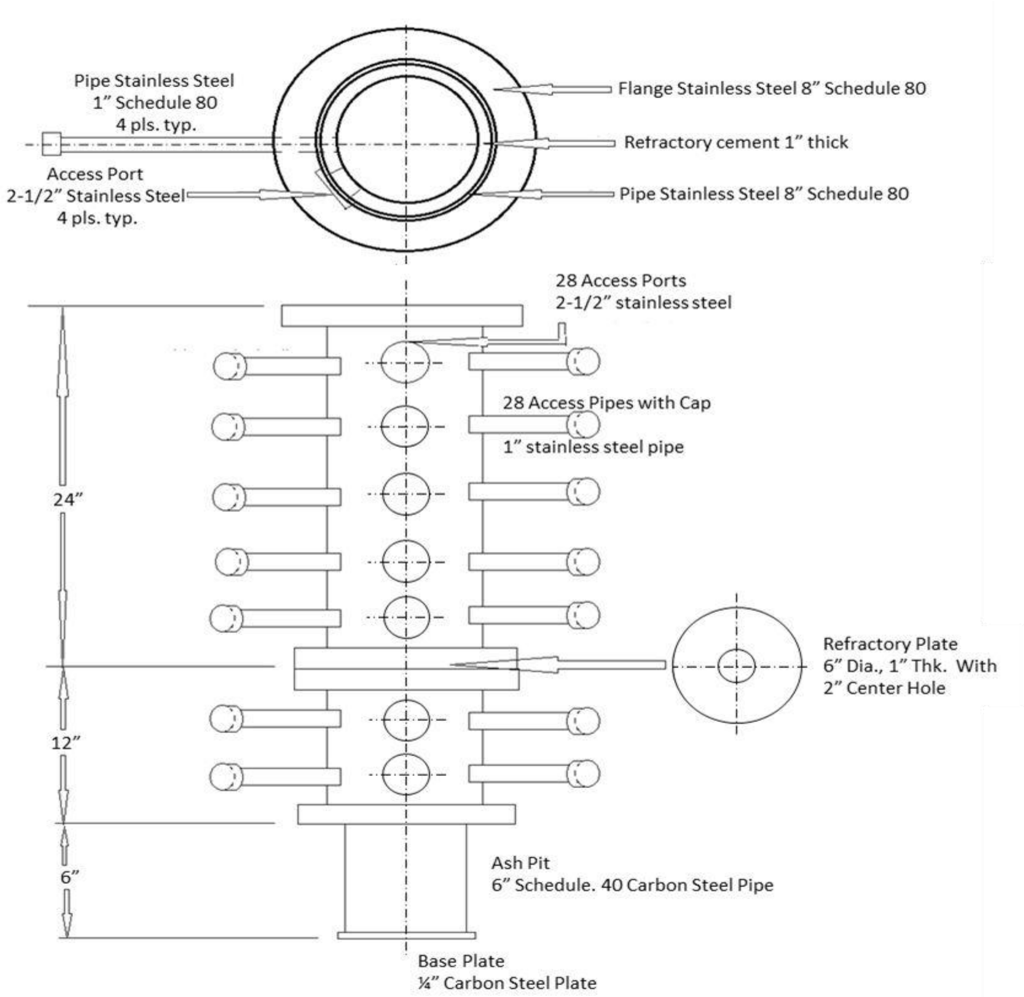

Fig. 2. CERF Gasifier Design Sketch

2. MATERIAL AND METHODS:

2.1 Materials

Wood chips for gasification were obtained from two sources. The first source consisted of willow *(salix)* woodchips of approximately 3/8"X3/8"X1/16" in size. The wood chips were air-dried to a 15% moisture content in a sunny room.

The chips were small and potentially excessively reducing air flow through the char-combustion zone. As a result, sugar maple *(acer saccharum)* hardwood chips were obtained. These sugar maple woodchips were between 28.58 mm (9/8 in), 15.88 mm (5/8 in) approximately in size and dried to a moisture content obetween 8 to 10%.

The willow and sugar maplewood chips were harvested from the State University of New York (SUNY), College of Environmental Science and Forestry (ESF) Tully and Heiberg Forest operation in Tully, NY.

The willow wood stems with a diameter between 30 mm and 50 mm and 2.10 m (8ft) in length were chipped with a commercial garden chipper. The harvested sugar maple logs with a diameter between 150 mm and 200 mm (6 in and 8 in) and 1.2 m (4 feet) in length were manually debarked and processed with a commercial Carthage wood chipper that allows the processing of a maximum log diameter of 200 mm. After chipping, the chips were screened with a vibrating shaker screen. The chip fraction that remained on the two perforated screens, 22.23 mm (7/8 in), 15.88 mm (5/8 in) was used for the gasification investigation.

Moisture content was analyzed by using a Denver Instrument IR-35 moisture balance.

2.2 Experimental Setup

Omega type K thermocouples (serial: SC-GG- K- 30- 36-PP) were soldered to extension thermocouple probes (McMaster-Carr K8R-12Z [Z773]) containing ceramic insulation and sealed into gasifier ports at various heights of the gasifier using silicone gel as shown in Fig. 2 above. Airflow sufficient to maintain a combustion zone temperature of 1000°C was provided by a 1 hp. Shop Vacuum Cleaner (SVC) and a 4" box fan. A vertically oriented radiator to cool the syngas was boxed in and piped to capture some of the gasifier heat of combustion and return it as warmed combustion air to the gasifier to maximize the combustion temperature. The boxed in radiator with piping and SVC and box fan are shown as components in the complete gasfier system in Figure 4 below.

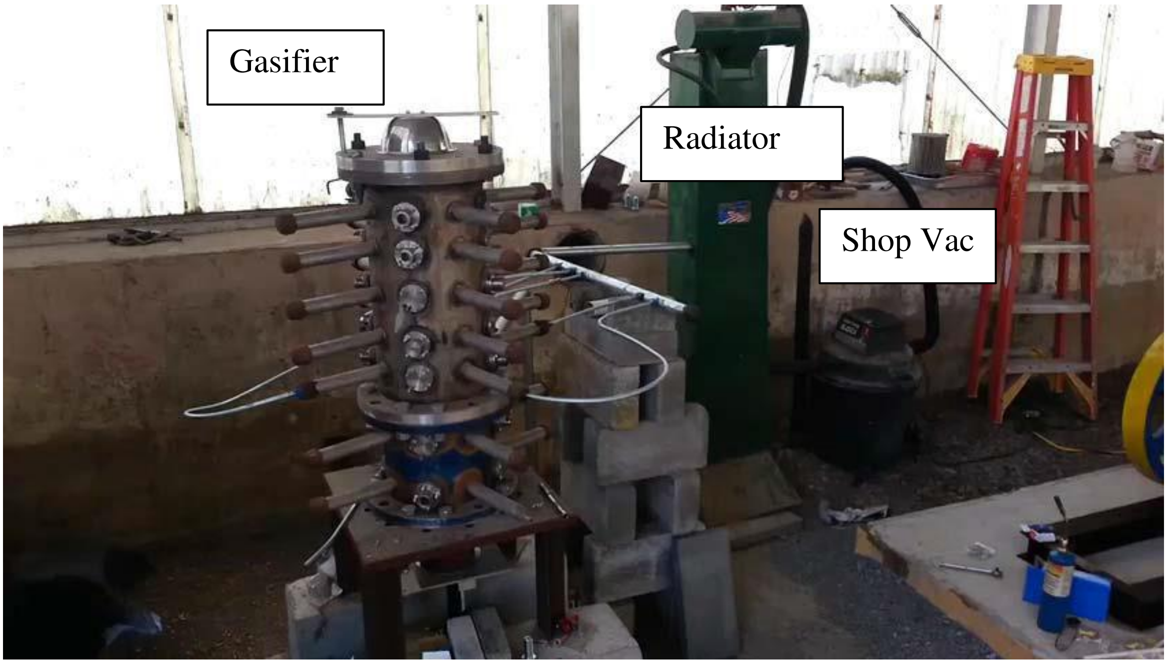

Fig. 4. Gasifier System

2.2 Experimental Procedure

2.1.1 Gasification Procedure

Wood chips were fed into the gasifier from the top and filled until approximately 1” below the top. Woodchips were pushed down in intervals of approximately 10-20 minutes during the run (when temperature of the material was generally stable). The pushing down of wood chips was to ensure that the chips dropped down into the combustion zone from the drying zone, to prevent bridging of the chips as the chips in the combustion zone were consumed. The gasifier was run in batches for a duration of 30 minutes (time taken to consume woodchips until reaching just above lighting port) consuming approximately 2 lbs. of woodchips each run. Shutdown of the gasifier occurred by shutting off the vacuum in order to stop drawing in air. During the gasifier run, the extension pipe on vacuum was occasionally changed between 2 different diameter pipes to control the air being drawn into the gasifier.

2.1.2 Temperature Measurement

A high temperature- data logger (Omega HH147) was used to view and manually record temperature. Due to difficulties with the data logger, temperature data could not be obtained for the port near the top of the gasifier. Temperatures were recorded at three different ports and reported in relation to the location of the lighting port (LP). The remaining ports are reported as above or below LP as LP+1 and LP -1 respectively. During preliminary and initial gasification experiments, temperatures were difficult to record (manually) due to fluctuation increments of up to 200°F within 30 second to 1minute intervals. Temperatures were recorded in 2 or 3 minute intervals for the majority of experiments.

2.1.2 Particle Size Measurement

Samples of particles were collected after the system was cooled for at least 12h from ports corresponding to heights of the temperature ports. A sample was retrieved from four different heights, the height just above the lighting port (LP+1), the height of the lighting port (LP), the height of the port below the lighting port (LP-1), and finally from the ash pit. These particle sizes were analyzed using sieve analysis. These particles were sieved with a W.S. Tyler RX-29 Sieve Shaker using ASTM E-11 US Standard test sieves with 4mm, 2mm, 300µm, 150µm openings. Material retained within each mesh was reported as percentage by weight using a Denver Instrument SI-234analytical scale.

3. RESULTS AND DISCUSSION:

Table 1: Nomenclature

Location	Abbreviation (based on location relative to lighting port [LP])
Ash	LP-1
Lighting Port	LP
Port just above Lighting Port	LP + 1
Port near top of gasifier*	LP + 2

*Temperatures were not reported for the thermocouple at the port near the top of the gasifier due to difficulties with the data logger memory and display.

3.1 Temperature Distribution

3.1.1 Temperature Distribution during gasification on Run1

This gasification experiment used the willow woodchips. The temperature profile for gasification run 1 shown in Fig. 5 below indicates that pyrolysis temperatures are achieved immediately in the gasifier; however, if gasification and combustion temperature zones were at all achieved, they may have only been achieved during quick fluctuations and were not maintained long enough for recording. This may have been due to the wood chips reducing air flow through the char-combustion zone. Drops in temperature can be attributed to cold woodchips being released when the wood chips were poked down.

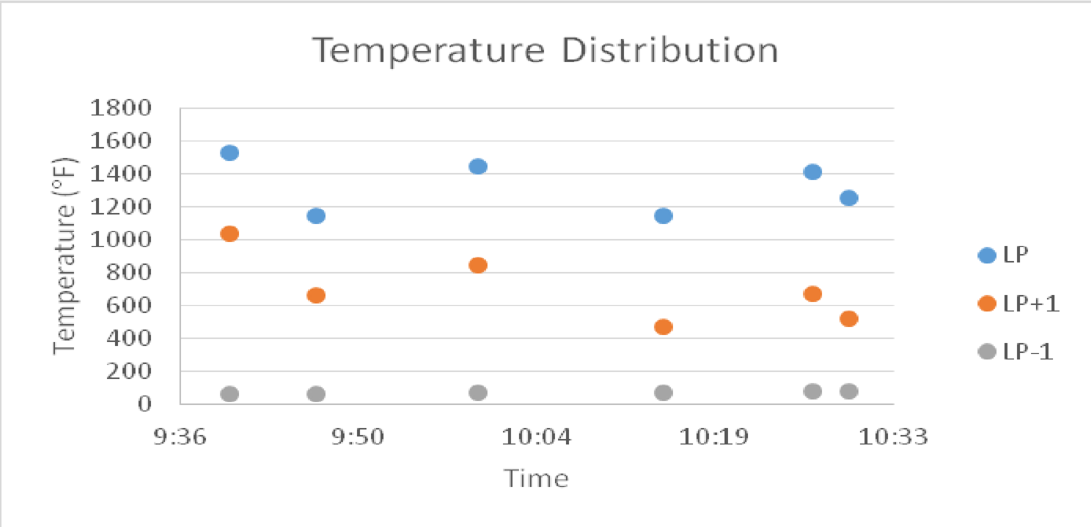

Fig. 5. Temperature Distribution along Gasifier during Gasification Run 1.

3.1.2 Temperature Distribution during gasification Run 2

In this gasification experiment, 1/4 of the wood chips in the gasifier were willow wood chips from the first experiment and 3/4 of the wood chips were sugar maple newly dried wood chips from the second source (the larger, more homogeneous chips). The wood chips from the first zone reached up to the lighting port region potentially affecting the temperatures in the lighting port region by blocking air flow through the zone. The region above the lighting port quickly reached pyrolysis temperatures but did not achieve any temperatures conducive to gasification and combustion as shown in Fig. 6 below.

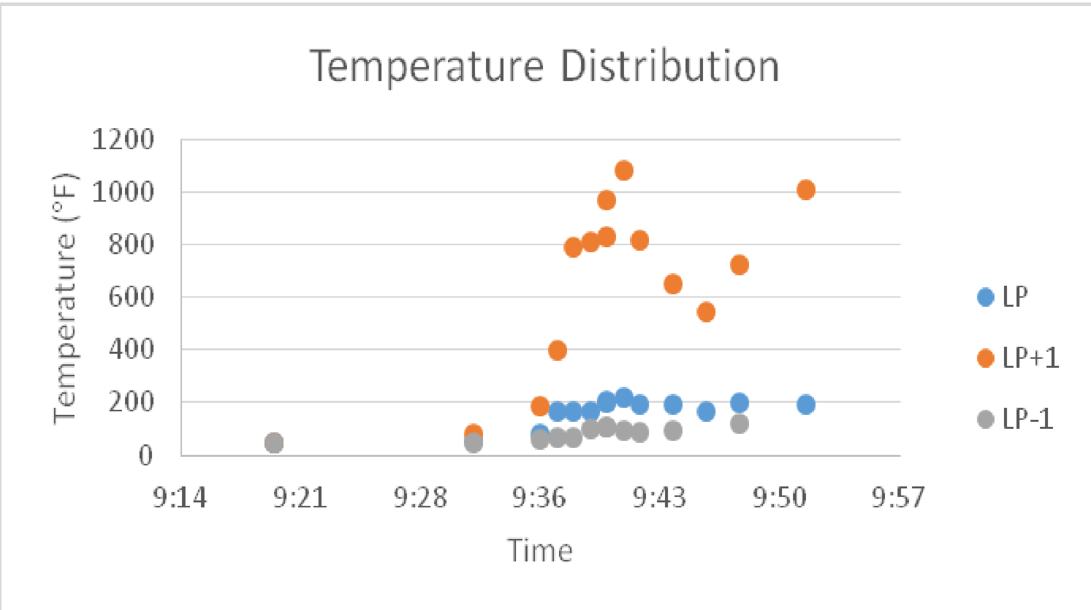

Fig. 6. Temperature Distribution along Gasifier during Gasification

3.1.3 Temperature Distribution during gasification Run 3

In this gasification experiment, the larger wood chips were added into the gasifier but some of the smaller pieces from the willow wood chips may have clogged up the gasifier below the lighting port zone which may explain the excessive smoke and fire in the gasifier that was evident near the end of the experiment. Temperatures within the gasification and combustion zone were reached for a brief period; however, the temperature recordings at the lighting port demonstrate the clogging in the gasifier likely disrupted the gasification and combustion processes as shown in Fig. 7 below.

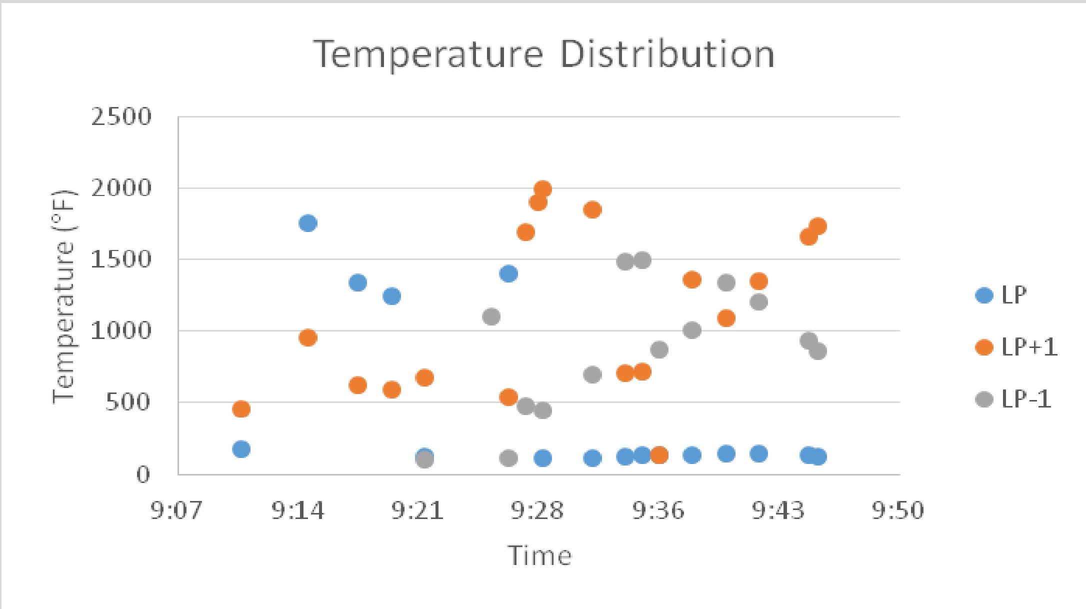

Fig. 7. Temperature Distribution Along Gasifier during Gasification

3.1.4 Temperature Distribution during gasification Run4

The temperature distribution profile for this experiment as shown in Fig. 8 below shows temperatures stable once achieving gasification and combustion temperature ranges. Some smoke was seen at approximately time 9:33 which may be a result of being at temperatures higher than gasification and combustion.

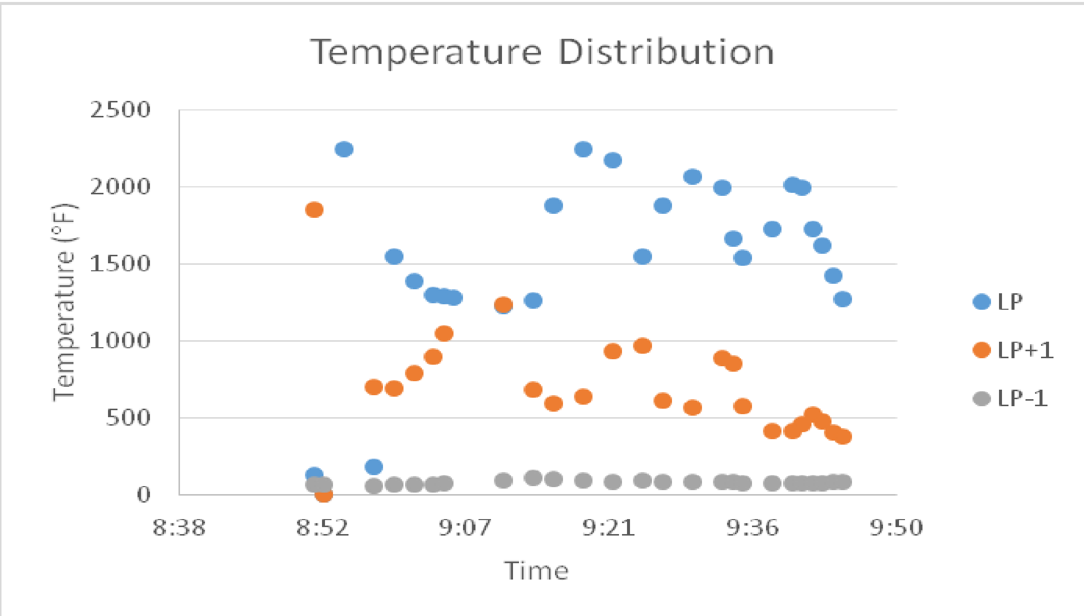

Fig. 8. Temperature Distribution Along Gasifier during Gasification

3.1.5 Temperature Distribution during gasification Run 5

Final gasification Run 5 temperatures are shown in Fig. 9 below. Pyrolysis temperatures were reached almost immediately. Furthermore, gasification and combustion temperatures were reached and maintained over the majority of the course of the experiment.

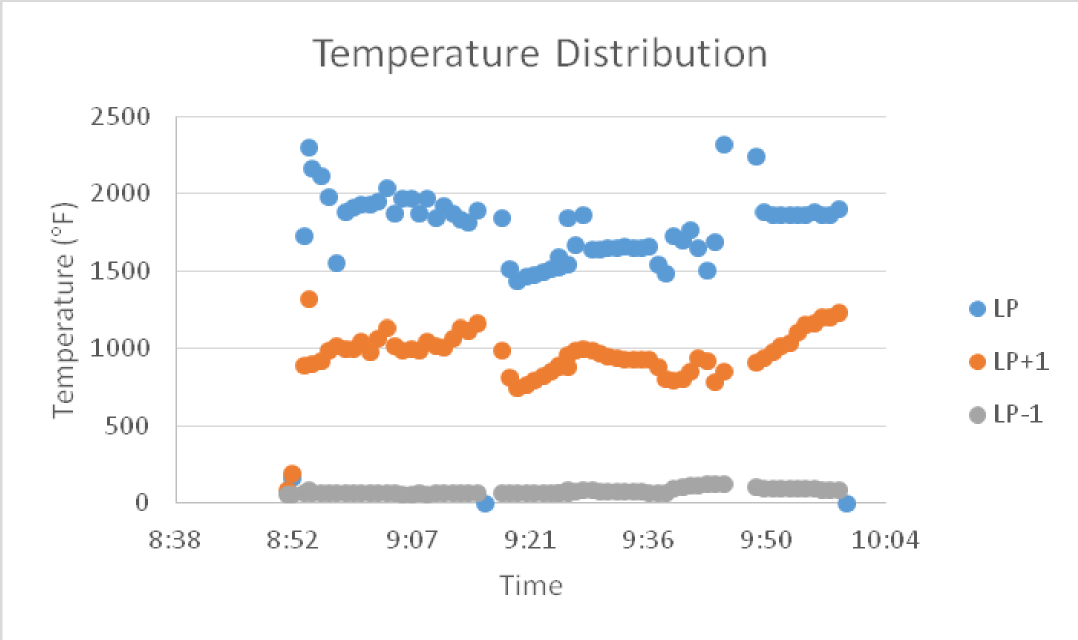

Fig. 9. Temperature Distribution Along Gasifier during Gasification

3.2 Particle Size Distribution using Sieve Analysis

The tables below provide the sieve analysis for each zone of the gasifier. The data does not include samples of Run 4 to prevent skewing of data as some of the wood chips were pushed down into the gasifier for the next run just before collection. The material residing in the lighting port is minimal in the majority of the gasification experiments as it is expected that those wood chips would have decomposed during the experiment. The only exception is the experiment from Run 3 where temperatures indicated clogging in the gasifier to be confirmed based on particle analysis as approximately 88% of the particles were larger chips. Quantities shown are in grams. Quantities of material collected in the gasifier level above the lighting port are shown in Table 1 below.

Table 1. Material just above Lighting Port (% Cumulative Wt Retained in Sieve)

LP+1	Run 1	Run 2	Run 3	Run 5
4mm	0.155	0	88.36018	N/A
2mm	0.0253	0	49.78038	N/A
300um	0.0067	0	37.4817	N/A
150um	0	0	0	N/A

The samples from the lighting port contain larger material; however, the evidence of clogging in the lighting port region on Run 3 can be seen here as well where ~92% of the cumulative weight is retained in the 300um mesh compared to 0-5% in the other gasification experiments. Material quantities collected from the lighting port level are shown in Table 2 below.

Table 2. Material from Lighting Port (% Cumulative Wt Retained in Sieve)

LP	Run 1	Run 2	Run 3	Run 5
4mm	77.9281	95.89744	32.67045	36.16208
2mm	45.99923	53.23077	70.17045	12.23242
300um	1.546193	0	91.71402	5.198777
150um	0	0	100	0

Below the lighting port, an increase in particle sizes on Run 2 indicates the clogging may have begun during this gasification run. The temperature profiles demonstrate lower temperatures in the lighting port which may have resulted in inadequate pyrolysis leaving larger wood chip pellets in the zone. No sample material resided in the zone just below the lighting port after the Run 3 gasification experiment. Possibly there was bridging at the lighting port or above and the material below burned out. Material quantities collected from below the lighting port are shown in Table 3 below.

Table 3. Material just below Lighting Port (% Cumulative Wt Retained in Sieve)

LP-1	Run 1	Run 2	Run 3	Run 5
4mm	66.36528	90.74476	N/A	62.3748
2mm	41.59132	73.31887	N/A	38.8269
300um	1.808318	26.3919	N/A	10.5866
150um	0	6.507592	N/A	0

Sample material collected from the Ash pit typically contained the largest amount of material and greatest portion of larger material as it is at the bottom. Limited oxygen and short residence time at combustion or gasification temperatures allow some of the biomass to pass through the gasifier to the ash pit as biochar. The ash pit generally contains up to 20% or so of biochar, a reactive charcoal that is highly desirable as a soil supplement. The downdraft pulling the producer gas through the reduction zone breaks down the larger complex hydrocarbons (tars) that can be so damaging to downstream filters and equipment. Material quantities collected from the ash pit are shown in Table 4 below.

Table 4. Ash (from Ash Pit) (% Cumulative Wt Retained in Sieve)

Ash	Run 1	Run 2	Run 3	Run 5
4mm	55.37256	60.64119	67.40227	84.8607
2mm	26.77765	29.45624	39.72608	50.07331
300um	3.976958	0.531171	10.08827	10.44721
150um	0	0.061797	0	0

4. CONCLUSION

The temperature profiles and sieve analysis together demonstrate that the gasifier is able to sustain temperatures and conditions required for all reaction zones of the gasification process between 700°C (1292°F) to 1000°C (1832°F) [7]. The gasifier was able to maintain temperatures above 1093°C (2000°F). The composition of the wood chips particularly in size, and secondarily in moisture content of the feed (fuel) into the gasifier is crucial to the proper functioning of the gasifier. It is suggested to use wood chips with a size between 28.58 mm (9/8 in), 15.88 mm (5/8 in) with a moisture content between 8% and 10%.

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