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Test Sample Production Report

Torrefaction of Ponderosa Pine Chips

Oregon Torrefaction

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Torrefaction of Ponderosa Pine Chips

Project Background

Oregon Torrefaction, LLC (OTL) and the US Endowment for Forestry and Communities has formed Restoration Fuels, LLC (RF) to construct and operate a 12 ton/h kiln torrefier which targets approximately 100,000 tons of torrefied woody biomass production annually. The plant will be co-located at the Malheur Lumber Mill, located in John Day, Oregon. Biomass sourcing will be principally small diameter, low-value wood from surrounding or nearby national forests including the Malheur and the Ochoco National Forests. The bulk of the woody biomass will be Ponderosa Pine from the dry land forests that surround John Day. Biomass coming from national forest areas have been evaluated for compliance with the US National Environmental Policy Act (NEPA) and are termed “shelf ready” for treatment. Restoration Fuels is now in the process of acquiring biomass supply to feed the torrefier. Early discussions with potential domestic and off-shore customers points to the need to have torrefied, densified test samples available for their evaluation, and it is in OTL’s interest on behalf of RF to produce a test batch of torrefied biomass that would be representative of RF’s future fuel product and to make samples available to serve customer interests. The effort is funded by the US Endowment and US Forest Service.

To accomplish the test sample production, the OTL provided 32.8 tons of wood chips to the Biomass Conversion Lab (BCL) located in Coleraine, MN for a sustained torrefaction production run using ponderosa pine as feedstock. The targeted specification for the torrefied wood chips as requested by OTL was 9,500 btu/lb. The BCL successfully torrefied and provided over 14 tons of torrefied feed stock to the OTL that met this targeted specification.

Program Challenges

During this production campaign, two challenges were overcome by the BCL production team. These challenges included:

1. The specified level of chip size was found to be larger than what was originally anticipated. This required the temporary set-up of a wood chipping circuit to take over-sized feed stock, chip it and recycle it back through the drying and torrefaction circuit. The BCL project team responded to this challenge by setting set up a Carthage chipper and subsequently feeding them back through the reclaim hopper. This allowed production time lines to be met while still meeting the specified tonnage amount of torrefied wood chips.

2. The residual tar-forming character for this material was significant and required reduced production rates, different tuning and center-lining techniques, increased clean out and inspections. The BCL project team overcame these challenges by tuning the system drying and torrefaction requirements to match the feedstock characteristics while meeting a targeted discharge torrefaction specification of 9,500 btu/lb. The center lining and process tuning capability demonstrated by the BCL project team to safely process and meet the production target for the ponderosa pine wood chips should be commended and was a significant milestone to overcome in the project.

Scope of Work and Results

The following sections layout the scope of work that was successfully completed, presents the torrefaction levels that were documented and achieved in this production campaign and present some of the key points and learnings throughout the project:

Step 1: Receive Biomass in Super Sacks and Stage for Production Runs

Key Points:

- OTL provided 32.8 tons of softwood pine wood chips shipped via super sacks. The super sacks were unloaded from the transportation provided by OTL using a fork truck. The sacks were stored outside the BCL. Wood chips were in the moisture content range of 40% to 55%.
- The BCL crew was not asked to record as-received wood chip weights marked on outside of super sacks to verify actual green wood chip weight added to outside feed circuit.
- Grab samples of as-received wood chips were collected from each truck delivery of super sacks. The samples were screen sized in the Batch Lab to determine the size distribution at 1”, ¾”, ½”, ¼” and 4 mesh of wood chips. The results showed an average of 52% plus ¾-inch chips in the as-received wood chips fed to the outside vibratory screen 1. The large proportion of oversized material necessitated the set of a temporary chipper to better manage the oversized feed stock and convert it to a size that was acceptable for the torrefaction process. The chipping circuit is shown in Figures 1 through 4 below.

Step 2: Torrefaction

Key Points:

- A staggered 12-hour day shift was incorporated for this trial to accommodate 5am to 5pm of operation.
- Super-sacks of green chips were emptied into the reclaim hopper which fed a conveyor belt that fed a vibratory screen. The rotary torrefaction kiln process was designed to torrefy material less than 3/4” size; the outdoor vibratory screen accepted chips that were -3/4” and +4 mesh. Over-sized chips (23.4 tons of as-received chips were greater than ¾” in size) were re-chipped to an acceptable size using a Carthage chipper.

Figure 1: Outdoor circuit conveying system.

Figure 2: Undersized (-4 mesh.) chips collected after screening.

Figure 3: Oversized (+ ¾ inch.) chips being fed to the chipper.

Figure 4: Oversized (+ ¾ inch.) chips collected after being resized by the chipper.

- Wood chips were dried to an average moisture content of 5.2% (with a standard deviation of 2.7%) before being fed to the kiln for torrefaction.
- Upon startup each day, the normal practice to achieve center-lining was to collect product via the Z-conveyor until the target HHV (High Heating Value) was achieved. Once HHV was achieved, torrefied chips were sent to Surge Bin #2. Each day Surge Bin #2 was filled and allowed to cool under nitrogen blanket overnight. Cooled and stabilized product was transferred from Surge Bin #2 into Type C super sacks provided by OTL.
- Excessive torr gas (smoke) emissions from the kiln was evident throughout this production run with the pine wood chips received from Oregon Torrefaction, LLC. This required kiln operators to use appropriate respirators for safety. The majority of torr gas leakage around the kiln was from the slide gate located at the bottom of kiln inlet feed breech. The slide gate was installed to remove any entrained wood chips that were held back in the kiln breech because of tar deposition. This was due to the high amount of volatiles that the ponderosa pine contained. The BCL project team was able to overcome this challenge by further fine tuning the system operational parameters.
- The following operational adjustments were made to reduce excess torr gas emission from kiln to the inside of Building 171:
    - The reduction of dryer and kiln feed rate to better manage volume rate production torr gas formed across the kiln.
    - The kiln drive speed was set at 50% or higher to prevent wood chips from spilling back from feed end of kiln into the kiln feed breech slide gate.
    - A lower addition of steam injected to the kiln was implemented to better manage the leakage of torr gas across the kiln breech seals. Too much steam created more positive pressure and forced more torr gas to leak out of kiln breech seal areas. This fine tuning allowed significantly less leakage across the kiln breech seals.
- The torrefied chips exiting the kiln were then cooled through a cooling screw to 250 ^{o}F and fed to surge bin 2. Surge Bin 2 was a live bottom bin with four screws to discharge the cooled chips. The sequence of conveyance through the bucket elevator and Surge Bin 2 mechanically degraded the friable wood chips into a finer state where approximately 50% of the chips were a fine powder with the balance being torrefied chips.

- Product produced in the first week was stored in 55-gallon drums because the Type C super sacks and static tester were not available until Sept 12, 2018.
- Type C super sacks of torrefied wood product had to be stored outdoors and exposed to rain for safety reasons. The torrefied wood moisture content increased significantly when stored outside.

Step 3: Product Testing

NRRI used its Bomb Calorimeter to measure the high heating value (HHV) of the torrefied wood. Per OTL, NRRI targeted 9,500 BTU/lb in the final torrefied product. Samples of torrefied chips were collected by redirecting product to the z-conveyor. During normal kiln operation one sample was taken per hour.

Figure 5: Picture of torrefied wood chips.

Key Points:

A Statistical summary of the targeted btu content for the torrefied chips is presented in Appendix A and Appendix B.

- The average Btu content logged by the BCL staff and taken over 149 samples was found to be 9,622 Btu/lb with a standard deviation of 327, well within the targeted range of 9,500 btu/lb.
- The average Btu content logged over 9 samples taken over a one-hour operating period averaged 10,005 btu/lb with a standard deviation of 246. This Btu content was recorded by Twin Ports Testing.
- In general, the X-Bar and Range charts shows that the targeted btu content is being acceptably achieved. Noted outliers are currently being investigated and scrutinized by the project team.
- The general trend in the Twin Ports Testing data showed that the heating values for the finer particles were slightly higher than the coarser particles but still were within a 300 BTU/lb range. This may indicate that finer material stays in the kiln longer or are more

easily “roasted” in the interior of the chips due to the higher surface area to volume ratio; this causes the finer chips to become more torrefied that the larger particles.

Step 4: Product Loading for Transport

NRRI used a fork truck to load forty-eight (48) Type C super sacks onto a low boy, flatbed truck. The total weight of wood chips loaded was ~12.2 tons (11.8 tons dry). However, 1.8 tons (1.75 tons dry) of torrefied product was sent to Jagannadh Satyavolu at the University of Louisville, so the total remaining weight sent to John Day, Oregon was 10.4 tons (10.1 tons dry).

Overall, the project received 32.8 tons (31.7 tons were plus 4 mesh) of raw wood chips at approximately 43% moisture content (18.7 dry tons; 18.1 tons plus 4 mesh), of which 12.2 tons were successfully converted and shipped as torrefied wood chips meeting a torrefaction specification of 9,500 btu/lb.

Table 1: Daily weights and average calorimeter values for torrefied product.

Date	Torrefied Wood Kiln Product (lbs)	Average Daily Torrefied Wood Calorimeter Value (BTU per lb)
7-Sep-18	211	9,444
10-Sep-18	528	10,003
11-Sep-18	1,142	9,630
12-Sep-18	1,055	9,781
13-Sep-18	1,663	9,568
17-Sep-18	1,459	9,499
18-Sep-18	629	9,572
20-Sep-18	912	10,514
24-Sep-18	1,728	9,441
25-Sep-18	1,808	9,744
27-Sep-18	2,229	9,543
1-Oct-18	1,799	9,440
2-Oct-18	1,801	9,481
3-Oct-18	2,072	9,448
4-Oct-18	1,696	9,478
8-Oct-18	1,346	9,541
9-Oct-18	2,293	9,794
Sum	24,370	---
Average	---	9,642

Appendix A:

Sub-report of calorimeter values for the entire project

Data Analysis for Oregon Torrefaction Data

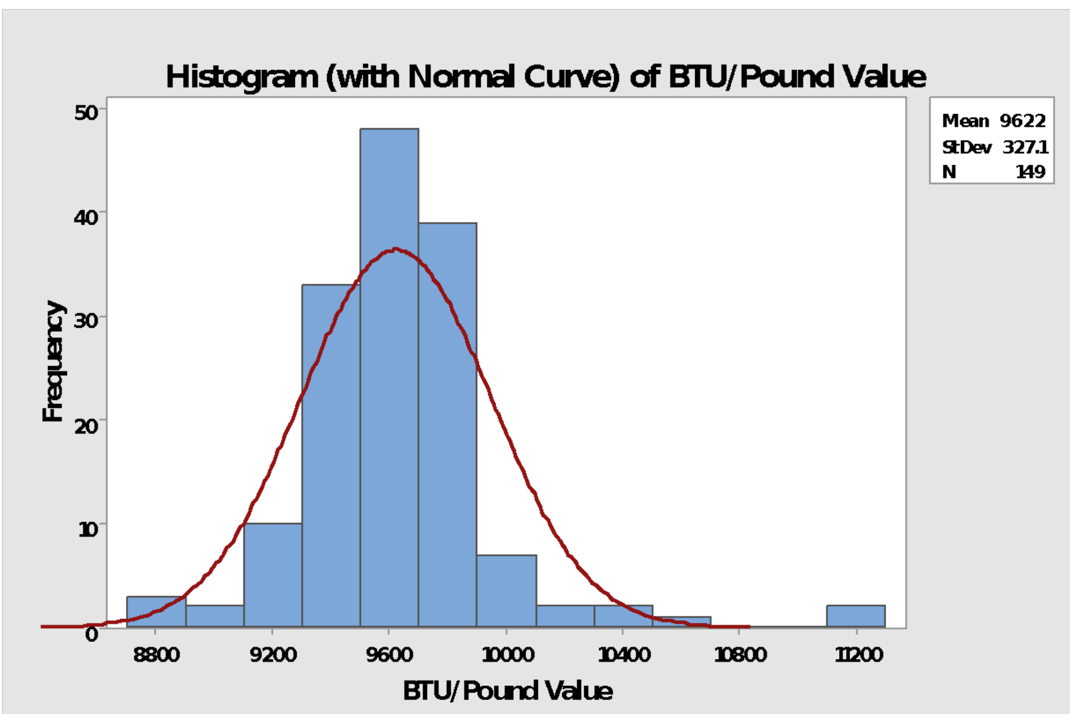
October 23, 2018

Objective

The objective of this study is to assess the process stability and performance for the Oregon Torrefaction production run at NRRI's Coleraine facility, September – October 2018.

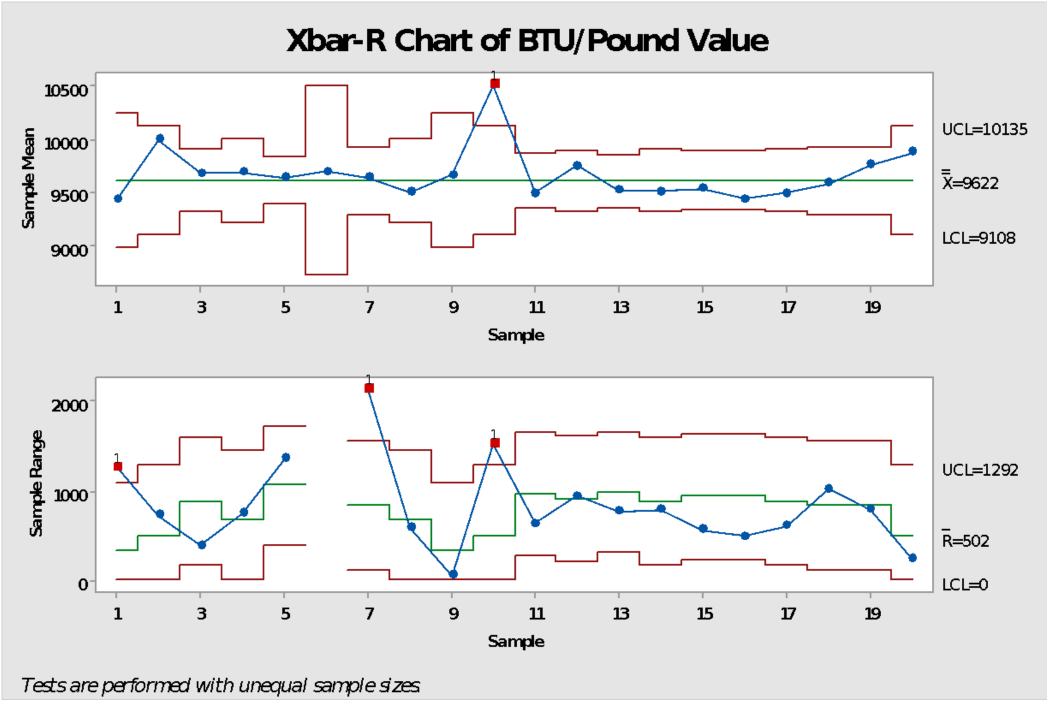
Analysis

The Oregon Torrefaction data analyzed in this report was from production run dates 9/6/18 - 10/10/18. The individual BTU data points were first plotted on a histogram, and key statistics were summarized.



On the histogram it is observed that a majority of the data falls between the bins centered at 8,800 BTU/lb and 10,800 BTU/lb, but there are two outliers that fall above 11,100 BTU/lb.

The data was next plotted on an X-bar and range chart, under the premise that the sample consisted of readings from one day (note that for this reason the sample size was variable, resulting in variable control limits on the chart). The control limits are slightly narrower than the process width noted above, as the variation surrounding each point is calculated based upon the standard error about the average- i.e., the variation of the samples collected over the span of one day.



There is one point outside the control limit on both the X-bar and range charts (point #10), and two others outside the control limit on the range chart only (#1 and #7). Note that there is a value plotted on the Xbar chart for point #6, but no corresponding value on the range chart. This is due to the fact that only one measurement was plotted from this day. In general, the trend charts reasonable control for achieving a targeted btu content of 9,622 btu/lb.

Summary

The analysis of the histogram and raw data summary statistics indicate that the majority of the data fall between 8,600 BTU/lb and 10,600 BTU/lb. There are two outliers in the data corresponding to readings of 11,270 BTU/lb and 11,153 BTU/lb. These values are further illustrated on the SPC charts, where they show a slight out control of situation. The staff at the BCL and the NRRI are looking into the causes for the noted outlier conditions.

Appendix B:

Sub-report of calorimeter values across various particle sizes

Twin Ports Testing submitted for heating value October 5, 2018

Objective: To demonstrate and validate that the uniformity of heating across the rotary kiln is consistent across fine, mid-size and coarse size wood chips.

Method: Twelve (12) composite samples of chips were collected over one hour during a steady state Oregon Torrefaction run on October 1, 2018. Three random samples were split (samples split were collected at least 20 minutes apart during the torrefaction process) into fine, mid and coarse fractions as listed below. Each sample size fraction was then passed through a nut grinder to a uniform particle of 100% passing 8 mesh (2.36 mm); grinding allowed proper mixing and a more representative sample to be created. The samples were then submitted for heating value analysis to ascertain any heating value differences across particle size fraction.

Hypothesis: Net retention time across the kiln is partially governed by particle size. A coarse particle size may migrate through the kiln at a slower rate than a finer particle size. That is, uniformity of particle size into the kiln will result in uniformity of heat transfer into the wood chip particles. A heating value analysis as listed above across particle size should help confirm this hypothesis. In addition, it may provide insight into the importance of the particle size distribution fed to the kiln.

Results: The general trend in the data from Table B1-1 shows that the heating values for the finer particles were higher than the coarser particles but still were within a 300 BTU/lb range. This may indicate that finer material stays in the kiln longer or are more easily "roasted" in the interior of the chips due to the higher surface area to volume ratio; this causes the finer chips to become more torrefied that the larger particles. *Over-torrefied material* can negatively affect the degree to which the materials can be properly densified, whereas any *under-torrefied material* can be a conduit for moisture penetration and will be difficult to grind in conventional pulverized coal grinding systems.

This is one of the reasons that BCL prescreens the chips to remove the large oversize material (+3/4 inch) and removes the fine – 4 mesh fraction before anything enters the drying and torrefaction process. This helps minimize the degree of torrefaction differences across particle size, which in turn eases any densification challenges for the material while also minimizing grindability challenges. Indeed, the uniformity of feedstock sizing to the kiln is one of the most important parameters to consider in any commercial torrefaction operation. Uniformity of feedstock sizing to the kiln helps to assure the following:

1. Uniformity of torrefaction level (kJ/kg or Btu/lb) across the kiln.
2. Eliminates over-torrefied or under-torrefied material from exiting the kiln.
3. Densification challenges are minimized because any over- or under-torrefied material is eliminated.
4. Densification challenges are minimized due to predictable particle size of torrefied chips fed into post-torrefaction grinder system. This allows a targeted particle size to be met for pelleting or briquetting.
5. The Hardgrove grindability (HGI) of the material is improved because any under-torrefied material has been minimized thereby eliminating any hard-to-grind tenacious fibers.

It should be noted that a micro chipper can routinely produce a well-defined particle size distribution without the need for pre- screening and can routinely yield 85 % retained between 3/8 and 1 /4 inch in size. Hence, an industrial sized micro chipper would be the ideally suited for feeding a torrefaction process plant tightly-sized microchips. The representative feedstock prepared from pine wood using a micro chipper is shown in Figure B1-1.

Figure B1-1: Microchipped feedstock.

Table B1-1: Calorimeter values across various particle sizes.

Sample I.D.	Size Fraction	Size Fraction mm	Size Range	Heating Value Btu/lb (dry)
A-1	-7/16 x 3/8	-11.11 mm x 9.52 mm	Coarse	10,073
A-2	-5/16 x 1/4	-7.4 mm x 6.35 mm	Mid	10,116
A-3	-4 x 8	-4.76 mm x 2.36 mm	Fine	10,094
B-1	-7/16 x 3/8	-11.11 mm x 9.52 mm	Coarse	10,087
B-2	-5/16 x 1/4	-7.4 mm x 6.35 mm	Mid	10,229
B-3	-4 x 8	-4.76 mm x 2.36 mm	Fine	10,375
C-1	-7/16 x 3/8	-11.11 mm x 9.52 mm	Coarse	9,583
C-2	-5/16 x 1/4	-7.4 mm x 6.35 mm	Mid	9,655
C-3	-4 x 8	-4.76 mm x 2.36 mm	Fine	9,839