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Arundo Donax Test Results

Corrie Nichol
Tyler L. Westover

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Objective:

Arundo Donax was received from Greenwood Resources via Portland General Electric. PGE plans to transition a coal-fired boiler to 100% biomass by 2020, and has partnered with EPRI and INL to conduct the necessary testing and development to understand what needs to take place to make this transition. Arundo Donax is a promising energy crop for biopower, and is as yet relatively untested and uncharacterized. The INL has begun initial characterization of this material, and this summary report presents the initial findings.

Test Methods:

Methods for testing various material parameters are discussed in more detail in the Appendix. Below is a summary of characterization methods.

Particle Size:

Particle size and shape were determined using a CamSizer dynamic image analyzer. This method allows the characterization of parameters that describe particle shape, as well as reporting a particle size distribution.

Chemical Composition:

Chemical composition analysis was conducted in house. Test procedures used for the determination of chemical composition are listed in detail in the appendix. Testing included Proximate, Ultimate (CHNO,S) and Heating Value.

Ash Composition:

Ash composition was conducted by an outside laboratory. The raw sample was calcined at 600 C prior to determination of the ash composition.

Results Summary:

Particle Size:

The results of the particle size distribution are summarized in Table 1, including shape aspect ratio, and mean particle size in two dimensions (see Figure 1 in appendix).

Table 1 Particle Characteristics of Arundo Donax from Camsizer (HORIBA Instruments, Inc., Irvine, CA) on 3/16 inch sieve.

Particle Characteristics	Arundo Donax
X_c min (s_{gw}), mm	0.413 (0.517)
X_{fe} max (s_{gw}), mm	0.932 (1.529)
1/SPHT[b]	1.978 (0.025)[a]
Aspect Ratio[b]	0.440 (0.002)[a]

[a]Standard deviation n=2

Chemical Composition:

The proximate analysis results are summarized in Table 2 below. The material received was shown to have a relatively low moisture content, and a rather high ash content.

Table 2: Ultimate/Proximate Analyses Results.

	Proximate (%theoretical dry basis)						Ultimate (% theoretical dry basis)				
Material:	MC	Vol	Ash	Fixed Carbon	HHV (btu/lb)	LHV (btu/lb)	H	C	N	O[a]	S
ArDo	4.5	63.1	18.1	14.3	6753	5443	5.52	38.7	2.0	35.5	0.2

Abbreviations: ArDo-Arundo Donax; MC-Moisture content; Vol-Volatile; HHV-Higher heating value; H-Hydrogen; C-Carbon; N-Nitrogen; O-Oxygen; S-Sulfur. [a] Oxygen by difference.

Ash Composition:

As stated previously, the elemental ash analysis was conducted at an independent laboratory. The results of this test are summarized in Table 4 below. As demonstrated in other independent testing not reported here, the chlorine and silicon contents are quite high.

Table 3: Ash Composition Analysis.

Sample	Basis	Si	Ca	P	K	Na	Mg	Al	Cl	Fe	S	Ti
ArDo	% of ash	58.4	4.4	2.1	13.0	1.7	2.8	6.8	3.2	3.6	2.4	0.6
	µg/g of sample	6255	720	211	2471	280	385	822	737	578	220	80

Appendix: Test Methods

Particle Size Characterization using Camsizer

A dynamic image analyzer Camsizer (HORIBA Instruments, Inc., Irvine, CA) equipped with two digital cameras was used to analyze particle characteristics. This method was reported to be highly correlated with a well accepted static/quantitative technique using light microscopy (r>0.9 for both aspect ratio and sphericity) (Miller).

Average particle size and size distribution were determined based on the ASABE forage sieve method (ASABE. 2008). Shape quantification was determined according to a standardized method developed by the International Organization for Standardization (ISO 9276-6, 2006; ISO 13322-2, 2008). Particle distribution was calculated based on volume, which was defined using an ellipsoid model (Fig. 1, Eq. 3.1). $X_{c\ min}$ is the greatest width of a particle projection at a right angle; this measurement is equivalent to the result obtained from sieving analysis because, with sieving, the particle passes through the mesh with its smallest dimension. $X_{Fe\ max}$ is the maximum Feret-diameter of the measured set of Feret diameter of a particle projection (Feret diameter is the distance between two tangents placed perpendicular to the measuring direction (Hawkins, 1993)).

$$V_{Ellipsoid} = \quad - \qquad (3.1)$$

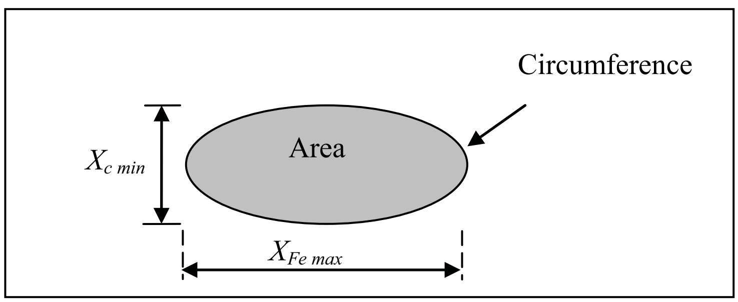

Figure 1 Two dimensional-particle model.

The series of sieves followed the Standard ANSI/ASAE S319.4 (ASABE. 2008), and were set in the software as follows: 6.7, 6.3, 5.6, 4.75, 4, 3.5, 2.8, 2.36, 2, 1.7, 1.4, 1.18, 1, 0.85, 0.71, 0.6, 0.5, 0.425, 0.355, 0.3, 0.25, 0.212, 0.18, 0.15, 0.125, 0.106, 0.09, 0.075, 0.063, 0.053, 0.045, 0.038, 0.032, 0.025 mm, and 0.02 mm (corresponding to sieve numbers 0.265", 0.25", #3.5, #4, #5, #6, #7,#8, #10, #12, #14, #16, #18, #,20, #25, #30, #35, #40, #45, #50, #60, #70, #80, #70, #80, #100, #120, #140, #170, #200, #230, #270, #325, #400, #450, #500, and # 635). Four parameters were analyzed, including:

i) Geometric mean diameter (d_{gw}), mm – the size at the 50% point on the plot of cumulative percentage under size (percentage of particles passing through a given sieve) versus particle size.

ii) Geometric mean diameter standard deviation (S_{gw}), mm – dimensions d_{84} and d_{16} are particle diameters at 84% and 16% probability, respectively.

$$= 0.5*[\ _{84} - \ _{16}] \qquad (3.2)$$

iii) Aspect ratio (dimensionless) – essentially a ratio of the width to the length of the ellipsoid silhouette, indicating elongation of particles (ISO 9276-6:2008).

$$\text{Aspect ratio} = \overline{\qquad} \qquad (3.3)$$

0≤value≤1; the ratio lesser than one indicates elongated particle, departing from equi-dimensional.

iv) Sphericity (dimensionless), (Retsch Technology, Haan, Germany).

(3.4)

The name sphericity suggested the comparison of surface area of a sphere, of the same volume as the particle, and the actual surface area of the particle (Wadell, 1932). However, Eq. 3.4 was proposed using two dimensional measurements and in fact related more on the circumference of particle projections. Cox (Cox, 1927) considered the calculation was more appropriate as roundness as it involved edges and corners of surface, instead of sphericity, which rather explained a form of a particle. Wadell also explained that roundness was a matter of the sharpness of corner, while shape had to do with the form of the particle. Pons (Pons et al., 1999) similarly considered roundness as it was more sensitive to the variations in surface roughness, and used it in the comparison of surface of the object to the surface of the disc of the same perimeter. In ISO 9276-6:2008, the square-root term of this Eq. 3.4 was referred to as circularity, indicating the degree to which the particle (or its projection area) is similar to a circle and therefore the smoothness of the perimeter. Miller (Miller) related this calculation to the qualitative angularity/roundness as it was strongly involved in particle surface irregularities. Today, the reciprocal (*1/SPHT*), value ≥ 1 is widely used; the names circularity shape factor or surface factor were given (Hausner; Hawkins, 1993). The factor increasing from unity designates a particle with a corrugated/irregular surface.

Chemical Composition:

Chemical composition testing was conducted using the following ASTM test methods:

Proximate:

%Moisture - (ASTM D 3172-07,3173-03) - Water content within the specimen lost after drying to 105°C.
%Volatile Matter - (ASTM D 3172-07, 3175-07) - That portion of a sample which is released before 950°C in the absence of air.
%Ash - (ASTM D 3172-07, 3174-04) - Usually inorganics, any material remaining after a specimen has been combusted (in the presence of oxygen) at ≥ 535°C.
%Fixed Carbon - (ASTM D 3172-07) - Remaining orgainic matter after volatile matter and moisture have been driven off.

Ultimate:

%Carbon - (ASTM D 3176-09) - Total elemental carbon content within specimen.
%Hydrogen - (ASTM D 3176-09) - Total elemental hydrogen content within the specimen.
%Nitrogen - (ASTM D 3176-09) - Total elemental nitrogen content within the specimen.
%Oxygen - (ASTM D 3176-09) - Total elemental oxygen content within the specimen (this is a calculated value).
%Sulfur - (ASTM D 4239-10) - Total elemental sulfur content within the specimen.

Calorimetry:

HHV - (ASTM D 5865-10) - Gross calorific content of a specimen
LHV - (ASTM D 5865-10) - Net calorific content of a specimen (this is a calculated value).