Combustion of single particles of Balsa, European Ash and Oak

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Co-firing biomass with coal

Near burner oxygen concentrations (note different oxygen scale in oak flame)

What biomass properties can we vary?

Physically possible to change the:
- Mass
- Shape
- Moisture content
- Fuel type
- Density

Economically possible to change the:
- ?
- ?
- ?
- Fuel type?
- Density?
Energy requirement of biomass milling

8% Moisture

12% Moisture

Shape, volume and surface area analysis
Moisture analysis

Balsa - 200 Deg C,
9.1200 mg

Balsa - oven dried,
4.4700 mg

Balsa - wet,
4.2000 mg

0  50  100  150  200  250  300  350  400  450  500
0  50  100  150  200  250  300  350  400  450  500

%
Moisture analysis

Balsa - 200DegC, 9.1200 mg
Balsa - oven dried, 4.4700 mg
Balsa - wet, 4.2000 mg
Vertically orientated wire mesh designed to heat a thermocouple (positioned near particle) to 900ºC.
Wire mesh apparatus

Vertically orientated wire mesh designed to heat a thermocouple (positioned near particle) to 900°C.
Particles of around 2-5mm in size are loaded between the meshes before the heating cycle is started.
Oak combustion

Oak, 23.4% Moisture, 20.38mg, Shape of 0.76, 35mm³.

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Oak combustion

Oak, 23.4% Moisture, 20.38mg, Shape of 0.76, 35mm³.
## Combustion experiments

<table>
<thead>
<tr>
<th></th>
<th>Low moisture content (dried at 205°C)</th>
<th>Low moisture content (dried at 105°C)</th>
<th>High moisture content (equilibrium at near 100% RH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balsa</td>
<td>16</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>European Ash</td>
<td></td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>Oak</td>
<td></td>
<td>14</td>
<td>21</td>
</tr>
</tbody>
</table>

Also intend to burn more fuels – Straw, Miscanthus, PKE
Burn out time – Oak – Effect of moisture

- Oak
- Linear fit

$R^2 = 0$
Burn out time – Oak – Effect of dry mass

![Graph showing the relationship between moisture residual (in seconds) and dry mass (in mg) for Oak. The graph includes a linear fit with an R² value of 0.81.](image)

- X X X Oak
- Linear fit

$R^2 = 0.81$
Burn out time – Oak – Effect of shape aspect ratio

$R^2 = 0.39$
Burn out time – Oak – Effect of density

![Graph showing the relationship between moisture, mass & shape residual (s) and density (kg/m^3)].

- Oak
- Linear fit

$R^2 = 0.08$
Combining the above linear trends we can form a regression model:

Burn out time (s) = -1.32 \times 10^{-3} \times \text{Moisture content (\%)} + 15.46 \\
+ 0.389 \times \text{Dry mass (mg)} - 6.65 \\
+ 14.7 \times \text{Shape aspect ratio} - 9.58 \\
+ 4.77 \times 10^{-3} \times \text{Density (kg/m}^3\text{)} - 2.82

This should account for 89\% of the variation in the data set.
Burn out time – Oak – Regression model

![Graph showing the relationship between measured and modelled burning times for oak. The graph includes the equation \( Y = X \) and the coefficient of determination \( R^2 = 0.89 \).]
## European Ash - Strength of effects

<table>
<thead>
<tr>
<th></th>
<th>Measured drying time</th>
<th>Devolatilisation ending time</th>
<th>Particle burn out time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation due to effect of moisture</td>
<td>0.63</td>
<td>0.10</td>
<td>0.04</td>
</tr>
<tr>
<td>Variation due to effect of dry mass</td>
<td>0.126</td>
<td>0.576</td>
<td>0.739</td>
</tr>
<tr>
<td>Variation due to effect of shape</td>
<td>0.010</td>
<td>0.211</td>
<td>0.097</td>
</tr>
<tr>
<td>Variation due to effect of density</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
</tr>
<tr>
<td>Variation which cannot be accounted for</td>
<td>0.234</td>
<td>0.113</td>
<td>0.124</td>
</tr>
</tbody>
</table>
## Oak - Strength of effects

<table>
<thead>
<tr>
<th></th>
<th>Measured drying time</th>
<th>Devolatilisation ending time</th>
<th>Particle burn out time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation due to effect of moisture</td>
<td>0.55</td>
<td>0.18</td>
<td>0.00</td>
</tr>
<tr>
<td>Variation due to effect of dry mass</td>
<td>0.072</td>
<td>0.459</td>
<td>0.81</td>
</tr>
<tr>
<td>Variation due to effect of shape</td>
<td>0.064</td>
<td>0.159</td>
<td>0.074</td>
</tr>
<tr>
<td>Variation due to effect of density</td>
<td>0.019</td>
<td>0.038</td>
<td>0.009</td>
</tr>
<tr>
<td>Variation which cannot be accounted for</td>
<td>0.295</td>
<td>0.164</td>
<td>0.107</td>
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</tbody>
</table>
# Balsa - Strength of effects

<table>
<thead>
<tr>
<th>Variation due to effect of moisture or heat treatment</th>
<th>Measured drying time</th>
<th>Devolatilisation ending time</th>
<th>Particle burn out time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.10</td>
<td>0.02</td>
<td>0.18</td>
</tr>
<tr>
<td>Variation due to effect of dry mass</td>
<td>0.018</td>
<td>0.55</td>
<td>0.52</td>
</tr>
<tr>
<td>Variation due to effect of shape</td>
<td>0.0088</td>
<td>0.034</td>
<td>0.012</td>
</tr>
<tr>
<td>Variation due to effect of density</td>
<td>0.323</td>
<td>0.032</td>
<td>0.064</td>
</tr>
<tr>
<td>Variation which cannot be accounted for</td>
<td>0.55</td>
<td>0.364</td>
<td>0.224</td>
</tr>
</tbody>
</table>
Combustion behaviour of Balsa, European Ash and Oak have been studied in a single particle wire mesh apparatus.

Drying times were found to depend upon moisture content, although there is some unexplained variation in the results.

Devolatilisation ending times were found to primarily depend upon dry mass, but also shape and to a lesser extent moisture content.

Burn out times were found to depend heavily upon dry particle mass (i.e. and not much else).
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