Quality and Productivity in Commination of Small Diameter Tree Bundles

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- Introduction to small-diameter tree bundles -

What we know:

• Bundling whole-trees from early thinnings has become an important assortment within Nordic bioenergy supply chains.

• Bundling technology has allowed the process of bundling small diameter trees from thinnings to be a viable option within the procurement process (Ala-Vari and Ovaskainen 2013, Bergström et al. 2015, Nuutinen and Björheden 2016).

• Operational competitiveness dependent on a variety of variables... stand characteristics and market prices.

• Reduction of supply chain costs via terrain and road transportation (Bergström and Di Fulvio 2014, Kärhä et al. 2009).
- Objective of the comminution and productivity study -

What we know:

• Quality of wood chips is dependent on technology and raw material utilized (Eriksson et al. 2013).
• Comminution of our forest raw material is primarily through chipping (cutting) and grinding (blunt impact) processes (Eriksson et al. 2013).

What we didn’t know:

• What are the measurable qualities of fuel wood chips produced from small-diameter whole tree bundles.
• Qualities and productivities produced by machine type and processing function.
- Methodology: Study design -

• The study was conducted in the municipality of Padasjoki (Central Finland) during March, 2014.
• Bundles were produced from small-diameter whole-trees utilizing a Fixteri FX15a small tree bundler in May, 2013.
  • **Approximate dimensions of bundles:** 2.6 m x 60 – 70 cm (0.6 m³ s.).
  • **Size of whole trees in bundles:** 15 – 35 dm³ (5 – 13 cm (dbh)) with average stem sizes of 25 dm³ (9 cm (dbh)).
  • **Composition:** ¼ Scots pine (*Pinus sylvestris* L.), ¼ Norway spruce (*Picea abies* (L.) Karst.), ¼ Downy birch (*Betula pubescens*), and ¼ Black alder (*Alnus Glutinosa*).
  • **Storage:** Roadside storage (2 months), terminal storage (6 months); Approximately 1,000 m³ s. of cross layered bundles 5 m in height were placed at the terminal study site.
  • **Comminution:** Six machine runs comminuting 327.4 m³ loose (128.4 tonnes).

<table>
<thead>
<tr>
<th>Machine model</th>
<th>Engine power [kW]</th>
<th>Diameter of chipping drum [mm]</th>
<th>Number of chipping blades</th>
<th>Dimension of infeed aperture [mm]</th>
<th>Dimension of sieves [mm]</th>
<th>Load space vol. [m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Volvo, 562</td>
<td>1300</td>
<td>2</td>
<td>1090x700</td>
<td>100, comb</td>
<td>54</td>
</tr>
<tr>
<td>B</td>
<td>Volvo, 525</td>
<td>860</td>
<td>10</td>
<td>1000x600</td>
<td>80x80</td>
<td>50</td>
</tr>
<tr>
<td>C</td>
<td>Mercedes Benz, 468</td>
<td>1040</td>
<td>24</td>
<td>1200x820</td>
<td>80x80</td>
<td>94</td>
</tr>
<tr>
<td>D</td>
<td>Cummins, 400</td>
<td>1440</td>
<td>4</td>
<td>1000x820</td>
<td>80x120</td>
<td>55</td>
</tr>
<tr>
<td>E</td>
<td>Cummins, 496</td>
<td>900</td>
<td>2</td>
<td>1000x720</td>
<td>120, comb</td>
<td>94</td>
</tr>
<tr>
<td>F*</td>
<td>Own, ≤ 330</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>97</td>
</tr>
</tbody>
</table>

*Machine type F may be equipped with various engine options up to 330 kW, chipper knife set up when producing wood fuel, diameter capacity of 610 mm, and 610x1524 mm mill opening.

†Measured volume loaded onto either trailer or trucks.
Time Study:
• Continuous time study occurred, each machine comminuting one load.
• Effective working time \((E_0h)\) varied 15 – 30 min.

Sampling and analysis of fuel chips:
• SFS- EN ISO 17225-1: Fuel quality classes and specification for solid biofuels.
• SFS- EN ISO 15149-1: Particle size analysis specification.
• SFS- EN ISO 15103: Bulk density.
• SFS-EN ISO 14774-2: Moisture content.
• Mass of wood fuel chips measured at the plant for each load.
• Three 50 dm³ chip samples were collected from different points immediately after loading.
• Sub samples were placed into plastic bags (combined in lab).
• Sample particle size determined with digressive diameter classes of sieves
  • 100 mm, 62 mm, 45 mm, 31.5 mm, 16 mm, 8 mm, 3.15 mm.
• Samples air dried to moisture content <20%, then sieved for 15 min.
• Particles of each sieve size weighed (accuracy .1 g).

<table>
<thead>
<tr>
<th>Class</th>
<th>Main fraction, minimum 60 w-% (mm)</th>
<th>Coarse fraction, w-% (mm)</th>
<th>Maximum length for oversized particles (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P16S</td>
<td>3.15&lt;=P=&lt;16</td>
<td>&lt;=6% &gt; 31.5 mm</td>
<td>&lt;=45 mm</td>
</tr>
<tr>
<td>P16</td>
<td>3.15&lt;=P=&lt;16</td>
<td>&lt;=6% &gt; 31.5 mm</td>
<td>&lt;=150 mm</td>
</tr>
<tr>
<td>P31S</td>
<td>3.15&lt;=P=&lt;31.5</td>
<td>&lt;=6% &gt; 45 mm</td>
<td>&lt;=150 mm</td>
</tr>
<tr>
<td>P31</td>
<td>3.15&lt;=P=&lt;31.5</td>
<td>&lt;=6% &gt; 45 mm</td>
<td>&lt;=200 mm</td>
</tr>
<tr>
<td>P45S</td>
<td>3.15&lt;=P=&lt;45</td>
<td>&lt;=10% &gt; 63 mm</td>
<td>&lt;=200 mm</td>
</tr>
<tr>
<td>P45</td>
<td>3.15&lt;=P=&lt;45</td>
<td>&lt;=10% &gt; 63 mm</td>
<td>&lt;=350 mm</td>
</tr>
<tr>
<td>P63</td>
<td>3.15&lt;=P=&lt;63</td>
<td>&lt;=10% &gt; 100 mm</td>
<td>&lt;=350 mm</td>
</tr>
<tr>
<td>P100</td>
<td>3.15&lt;=P=&lt;100</td>
<td>&lt;=10% &gt; 150 mm</td>
<td>&lt;=350 mm</td>
</tr>
<tr>
<td>P200</td>
<td>3.15&lt;=P=&lt;200</td>
<td>&lt;=10% &gt; 200 mm</td>
<td>&lt;=400 mm</td>
</tr>
<tr>
<td>P300</td>
<td>3.15&lt;=P=&lt;300</td>
<td>must be reported</td>
<td></td>
</tr>
</tbody>
</table>

Proportion of fines (<3.15 mm)
• F05 <= 5%
• F10 <= 10% Requirement for P31S and P45S
• F15 <= 15% Requirement for P16S
• F20 <= 20%
• F25 <= 25%
• F30 <= 30%
• F30+ >=30% Max value must be reported
- Results of the comminution and productivity study -

Table 3. Particle size classes for chips comminuted for studied machines by SFS-EN ISO 17225-1, mean particle size, moisture content, moist and dry bulk density.

<table>
<thead>
<tr>
<th>Machine type</th>
<th>Main fraction class [w-%]</th>
<th>Fine fraction class [w-%]</th>
<th>Mean particle size50% [mm]</th>
<th>Moisture content [w-%]</th>
<th>Moist bulk density after chipping [kg/m³]</th>
<th>Dry bulk density [kg/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>P31S (66.8)</td>
<td>F15 (12.2)</td>
<td>16.08</td>
<td>51.9</td>
<td>371</td>
<td>178</td>
</tr>
<tr>
<td>B</td>
<td>P31S (61.3)</td>
<td>F30+(33.7)</td>
<td>5.79</td>
<td>59.9</td>
<td>417</td>
<td>167</td>
</tr>
<tr>
<td>C</td>
<td>P31S (77.2)</td>
<td>F10 (5.4)</td>
<td>20.64</td>
<td>54.7</td>
<td>353</td>
<td>160</td>
</tr>
<tr>
<td>D</td>
<td>P31S (80.1)</td>
<td>F15 (13.5)</td>
<td>13.02</td>
<td>51.9</td>
<td>369</td>
<td>177</td>
</tr>
<tr>
<td>E</td>
<td>P16 (60.4)</td>
<td>F15 (13.6)</td>
<td>10.93</td>
<td>55.0</td>
<td>351</td>
<td>158</td>
</tr>
<tr>
<td>F</td>
<td>P456 (67.5)</td>
<td>F20 (19.5)</td>
<td>12.30</td>
<td>58.0</td>
<td>259</td>
<td>109</td>
</tr>
</tbody>
</table>

Figure 1. Particle size distribution of comminuted wood fuel chips.
- Results of the comminution and productivity study -

Figure 2. Cumulative particle size distribution of fuel wood chips.

Figure 3. Effective hour chipping productivity (t/E₀h) of forest chips by dry mass basis and distribution of working time among tested machines.
- Discussion and conclusion: Quality -

Moisture content:
• High moisture content (52 – 60%) and plant requirements.
  • Bundle storage size and configuration.
• No trend identified between sieve size and moisture content, as previously (Jylhä 2013).
• Machine type B: Moisture content 60% and 33.7% F particles <3.15 mm diameter.

Particle size:
• Mean particle size variation 5.79 – 20.64 mm.
• Dry bulk density 109 – 178 kg/m³.
• 8.4 – 46.6% of the dry mass of whole-tree bundles was within 16 < 31.5 mm.
• Machine type B.
• Machine type F.
**Discussion and conclusion: Productivity**

**Time study:**
- Swinging boom towards bundle stack (25%).
- Transferring grapple bunch to chipper (28.4%).
- Feeding the grapple bunch into the chipper (26.2%).

**Productivity:**
- Dry mass basis productivity varied 29.8-71.3 t/E₀h with a mean of 52.2 t/E₀h.
  - Whole-tree bundle productivity at 32 t/E₀h (Kons et al. 2015).
  - Terminal vs. roadside comminution.
  - Dry mass productivities of logging residues (29 t/E₀h), whole-trees (25 t/E₀h) and stumps (17 t/E₀h); mean weight of grapple bunch 119 – 237 kg (Nuutinen et al. 2014).
  - Average weight of grapple bunch of chippers was 466 kg.
Thank you for your attention!

Further information on the study: Quality and productivity in comminution of small-diameter tree bundles.

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References:

Ala-varvi T, Ovaskainen, H. (2013): Kokopuun paalauksen kilpailukyky [Internet] [Competitiveness of whole tree bundling]. Metsäteho report 225. ISSN 1796-2374; 77 p; [cited 2015 Jul 23], [In Finnish with English summary].


