Investigation on optimisation of kiln drying of the bamboo species

*Bambusa stenostachya, Dendrocalamus asper* and *Thyroostachys siamensis*

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Introduction

Some important reasons to dry bamboo

- key step in processing of high quality bamboo products
- improve properties of bamboo in life
- add further value to bamboo recourse by the successful export of bamboo products into high value markets
Drying methods

Disadvantages of the traditionally used air drying
- long drying time
- bamboo can be infected by mould
- depends largely on climatic conditions and
- undertaken under uncontrollable conditions

Advantages of kiln drying
+ full control of drying conditions
+ better control of the required final moisture content
+ ensuring high level bamboo dried quality and
+ more efficient than air drying for large-scale drying operations
Problems with bamboo drying in Vietnam and other bamboo countries

The demand for the export of large quantities of quality products recently increased

Disadvantages of air drying

The development of bamboo kiln drying rarely supported by adequate research efforts
Aim of the research

To develop suitable kiln drying schedules for culm parts of the commercial species *Bambusa stenostachya*, *Dendrocalamus asper* and *Thyrodstachys siamensis* for furniture making.
## Experimental

### Bamboo samples

Table 1: The dimensions of the samples tested in the study

<table>
<thead>
<tr>
<th>Species</th>
<th>Length (in mm)</th>
<th>Average diameter (in mm)</th>
<th>Average wall thickness (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic</td>
<td>Middle</td>
<td>Basic</td>
</tr>
<tr>
<td>T. siamensis</td>
<td>1400</td>
<td>1400</td>
<td>45</td>
</tr>
<tr>
<td>B. stenostachya</td>
<td>1400</td>
<td>1400</td>
<td>80</td>
</tr>
<tr>
<td>D. asper</td>
<td>1400</td>
<td>1400</td>
<td>88</td>
</tr>
</tbody>
</table>
Dry-Kiln

- Temperature up to 90°C by electrical heating coils
- Climate control by hot water spraying and venting
- Air velocity at a constant speed of 3.5 m/s
- PLC controller process visualisation in real time
Kiln Drying

- For the drying of *Thyrotragys siamensis* 154 samples were stacked in 11 rows with 1 cm distance.
- For *Bambusa stenostachya* and *Dendrocalamus asper*, 64 samples were stacked in 8 rows.
- Five controls of the sample lot were used to estimate the average moisture content and moisture loss.

Stacking middle parts of *T. siamensis* and *D. asper*
Drying schedules

Table 2: The conditions (set-point values) of the four drying schedules

<table>
<thead>
<tr>
<th>Step</th>
<th>Moisture content (%)</th>
<th>No.1 T(°C)</th>
<th>No.1 RH (%)</th>
<th>No.2 T(°C)</th>
<th>No.2 RH (%)</th>
<th>No.3 T(°C)</th>
<th>No.3 RH (%)</th>
<th>No.4 T(°C)</th>
<th>No.4 RH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Over 90</td>
<td>45</td>
<td>80</td>
<td>50</td>
<td>80</td>
<td>55</td>
<td>80</td>
<td>65</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>90 - 70</td>
<td>45</td>
<td>70</td>
<td>50</td>
<td>70</td>
<td>55</td>
<td>75</td>
<td>65</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>70 - 50</td>
<td>50</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>65</td>
<td>70</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>50 - 40</td>
<td>50</td>
<td>50</td>
<td>60</td>
<td>50</td>
<td>65</td>
<td>50</td>
<td>70</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>40 - 30</td>
<td>50</td>
<td>40</td>
<td>60</td>
<td>30</td>
<td>65</td>
<td>35</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>30 - 20</td>
<td>55</td>
<td>40</td>
<td>65</td>
<td>30</td>
<td>70</td>
<td>25</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>7</td>
<td>20 -10</td>
<td>55</td>
<td>30</td>
<td>65</td>
<td>20</td>
<td>70</td>
<td>20</td>
<td>75</td>
<td>15</td>
</tr>
</tbody>
</table>

Conditioning with 50°C T and 70% RH
Determination moisture content (MC)

- **The initial MC of the control sample** was estimated from the moisture sections cut from each end of the control sample.

- **The average initial MC** was determined from moisture sections of five controls and five further samples.

Method of cutting sample control and moisture sections for initial MC
MC of the moisture sections was measured by oven dry method and calculated as

\[ \text{MC} (\%) = \frac{W_{or} - W_o}{W_o} \times 100 \]

\( W_{or} \) as original weight and  
\( W_o \) as oven dry weight of section

The oven-dry weight of control sample (\( W_{oc} \)) was computed by using the following formula:

\[ W_{oc} = \left( \frac{W_{or}}{100} + \text{AMC} \right) \times 100 \]

\( W_{or} \) as original weight of control sample  
AMC as average moisture content of two sections
Table 3: The average initial moisture content of the four experiments with samples n= 20

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Species</th>
<th>T. siamensis</th>
<th>B. stenostachya</th>
<th>D. asper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture content</td>
<td>Basic</td>
<td>Middle</td>
<td>Basic</td>
</tr>
<tr>
<td>No. 1</td>
<td>Mean (in %)</td>
<td>-</td>
<td>-</td>
<td>103</td>
</tr>
<tr>
<td></td>
<td>SD (in %)</td>
<td>-</td>
<td>-</td>
<td>6.8</td>
</tr>
<tr>
<td>No. 2</td>
<td>Mean (in %)</td>
<td>120</td>
<td>110</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>SD (in %)</td>
<td>8.8</td>
<td>7.2</td>
<td>6.1</td>
</tr>
<tr>
<td>No. 3</td>
<td>Mean (in %)</td>
<td>119</td>
<td>106</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>SD (in %)</td>
<td>8.1</td>
<td>7.2</td>
<td>6.4</td>
</tr>
<tr>
<td>No. 4</td>
<td>Mean (in %)</td>
<td>120</td>
<td>108</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SD (in %)</td>
<td>8.2</td>
<td>7.1</td>
<td>-</td>
</tr>
</tbody>
</table>
• The moisture gradient and the final average MC was evaluated by sections taken from both ends and from the middle of the samples (n=13).

Method of cutting moisture content sections for final MC
Drying rate, drying defects

**The drying rate** was determined by the relationship between moisture loss over drying time.

**Drying defects**
- All culms of the drying experiment were visually inspected for defects like collapse, cracking, and splitting that had occurred during drying.
- Drying defects were expressed as percentage of all samples in each kiln run.
Results

Drying rate and moisture loss

Relationship between drying time and moisture loss of *T. siamensis*
Relationship between drying time and moisture loss of *B. stenostachya*
Relationship between drying time and moisture loss of *D. asper*
Final moisture content

The average final moisture content with $n = 39$ of the four experiments.
Drying time & drying defects

T. siamensis

Drying time and percentage of defects for T. siamensis
Drying time and percentage of defects for *B. stenostachya*
Drying time and percentage of defects for *D. asper*
End checks of *T. siamensi* and *D. asper*
Conclusion

- The initial experiments have shown that kiln drying of bamboo parts can be conducted successfully using proper schedules of temperature and relative humidity.

- Drying the solid species *Thyrocastachys siamensis* requires a severe drying schedule at the initial stage with high temperature 65°C and 80% RH and temperature 75°C with low relative humidity of 15% at the final step.
The cavity species *D. asper* is a difficult species to dry and susceptible to drying defects. Therefore it needs a mild schedule with initial temperature of 45°C and initial RH of 80% and a final temperature of 55°C and RH of 30%.

*B. stenostachya* dried moderately fast using the relative milder schedule in an initial phase with T of 50°C and RH of 80% and an end step with 65°C and RH of 20%.
Recommendations

• The dry-kiln industry in South Vietnam will apply these effective and feasible schedules for drying longer culms.

• Also the drying schedules will be further developed for bamboo treated with preservatives based on boron compounds, CCB....

• Since drying is an essential step for processing bamboo into final products, the investigations should also include other commercial species
Acknowledgments

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Thank you for your attention!