

PALLET PHYTOSANITARY PROJECT BULLETIN



A Cooperative Effort of the Limestone Bluffs Resource Conservation and Development Area And The Wood Education and Resource Center USDA Forest Service

Number 10

January 2005

HEAT STERILIZATION TIMES OF SIX SIZES OF FIVE HARDWOOD SPECIES¹

This bulletin summarizes the results of the above titled research project funded under the Competitive Grants Program of the Pallet Phytosanitary Project.

INTRODUCTION

Current regulations for heat sterilization of wood packaging material (WPM) require holding a temperature of 133°F for 30 minutes at the core of each piece. An important factor in heat sterilization is the additional time required to reach these conditions at the core of any WPM configuration. Knowing this additional time will be useful in equipment planning and sizing. And, if reliable estimates of this heating time can be developed, they can serve as useful guidelines for specifications.

The objectives of this research were to:

- Determine the extent to which hardwood species commonly used in pallets affect the time required to heat the center of pallet components to 133°F at a heating temperature of 160°F.
- Determine the effect of common pallet part sizes on heating time.
- Determine if an available two-dimensional solution to the heat conduction equation is able to reliably estimate heating times in steam conditions.
- Determine how much heating time is extended when the heating is not saturated steam.

Several factors affect heating time and if all are allowed to vary it can be difficult to estimate heating time. Wood species, specific gravity, and moisture

¹ The researchers on this project were John W. Forsman and John R. Erickson (Michigan Technological University), William Simpson (USDA Forest Service, Forest Products Laboratory), and Xiping Wang (University of Minnesota-Duluth).

content can affect thermal conductivity and thereby thermal diffusivity that dictates rate of heat flow. Initial wood temperature also affects heating time – the lower the initial temperature the longer the heating time. Wood dimensions cause heating time to increase proportionally to the cross-sectional dimension – an 8” x 8” timber takes four times as long to heat as a 4”x4” timber. The heating medium will minimize heating time when the medium is saturated steam, where no simultaneous drying can occur. As the medium becomes less water saturated, heating times are prolonged, because the evaporation of water from the drying wood cools the surface and reduces the temperature difference between the surface of the wood and the core. Finally, stacking arrangements where the heating medium can access all surfaces of the wood yields the fastest heating time.

METHODOLOGY

Five hardwood species were tested, including: red oak, sugar maple, red maple, basswood, and aspen, all cut from freshly harvested logs. Within each species six sizes were tested: 1, 1 ½, 2-inch thick (all 6 inches wide and 8 feet long), 3x3 inch, 4x4 inch, and 6x6 inch by 8 feet long. Two heating mediums (both at 160°F dry-bulb temperature) were tested; saturated steam (steam spray on, only a 1-2°F wet-bulb depression) and heating with a wet-bulb depression of 10°F. All six sizes were heated together in a common test run, requiring ten test runs (5 species times 2 heating mediums). Each board size was replicated 5 times, with each replicate fitted with a thermocouple. Moisture content and specific gravity of each board were then measured.

RESULTS

Empirical Approach

Table 1 summarizes the average heating times required to reach 133° F at the center of each piece size.

Wet Bulb Depression	Piece Size	Heating Times to 133°F by Species (minutes)				
		Red Maple	Sugar Maple	Red Oak	Basswood	Aspen
1-2° F	1” x 6”	13.2	12.2	13.9	12.7	13.0
	1.5” x 6”	29.3	27.1	27.5	22.9	28.1
	2” x 6”	49.1	45.2	49.4	43.6	48.8
	3” x 3”	53.9	55.5	56.0	45.8	60.0
	4” x 4”	108.1	103.9	106.4	92.3	108.9
	6” x 6”	254.9	250.2	256.6	206.3	253.9
10° F	1” x 6”	16.7	13.9	14.5	15.1	14.6
	1.5” x 6”	36.9	32.8	31.6	27.9	29.8
	2” x 6”	58.4	55.1	56.0	58.0	54.8
	3” x 3”	84.5	64.0	66.7	62.1	66.8
	4” x 4”	133.7	124.4	126.0	113.7	125.1
	6” x 6”	294.4	295.0	294.7	258.5	276.5

Average specific gravity (SG) and average moisture content (MC) for each species were as follows: Red Maple (SG = 0.531 and MC = 65%); Sugar Maple (SG = 0.582 and MC = 50%); Red Oak (SG = 0.551 and MC = 75%); Basswood (SG = 0.327 and MC = 115%); and Aspen (SG = 0.398 and MC = 88%).

The results in Table 1 reflect some variation in heating times due to three factors:

- Variation in piece thickness due to sawing variation
- Differences in initial temperature of boards, due to the lack of controlled temperature facilities.
- Actual heating temperature varied slightly from run to run (the overall average actual heating temperature was 157° F).

The authors provide an adjustment in heating times, reflecting the above three factors, to improve the comparison of the heating times of the five species. This adjustment was made with the help of MacClean's² heat conduction equation, where cross-sectional dimensions, initial temperature, and heating temperature are the pertinent variables. A multiple linear regression relationship was developed relating heating time to the linear combination of the three variables.

A statistical analysis of the adjusted heating time results showed some significant effects. First, piece size had a significant effect on heating time, ranging from about 15 minutes for 1-inch thick boards to nearly 300 minute for 6" x 6" squares. Second, heating time was significantly longer with the 10° F wet-bulb depression heating than with the 1-2° F wet-bulb depression heating. The overall average increase in heating time for all species and all sizes was 15 percent. Finally, species had a statistically significant effect on heating time, but not all individual pairwise comparisons between species were significant. However, the actual effect of species was not large, so that there is no practical reason to heat-treat these five species separately. In effect the differences in heating times are of a similar magnitude to the expected natural variability between individual boards and squares.

Analytical Approach

The purpose of an analytical approach is to provide a method to calculate estimates of heating times based on the factors affecting it. Two analytical methods were applied to determine their ability to calculate estimates of heating times, using the unadjusted experimental results as a basis for comparison.

One method was the use of MacClean's (1932) equations. The other was a 2-dimensional finite difference solution to the differential heat flow equation with the boundary condition of variable temperature (Simpson, 2004)³, which is necessary during the use of dry heat where the surface of the wood is cooling from the evaporation of water during drying.

²MacClean, J. D. 1932. Studies of heat conduction in wood. Part II. Results of steaming green sawed southern pine lumber. In: Proceedings of American Wood Preservers' Association. 28:303-329.

³ Simpson, W. T. 2004. Two-dimensional heat flow analysis applied to heat sterilization of ponderosa pine and Douglas-fir square timbers. Wood and Fiber Science 36(3):459-464.

The most significant result of the analytical approach was that the wet-bulb temperature can be used successfully with the MacClean equations as the heating temperature. The percent deviation of the calculated times, based on MacClean's equations, and the experimental times resulted in an overall average absolute deviation of 7.1 percent. This allows the use of the heating tables published by Simpson (2001)⁴ that are based on the MacClean equations in applications other than heating in saturated steam. That is, when there is a wet-bulb depression during the use of dry heat.

CONCLUSIONS

The research produced a number of interesting and useful results. First, the actual effect of species was not large, so that there is no practical reason to heat-treat the five species investigated here separately. And, by extension, it should not be necessary to heat-treat any of the hardwood species separately. Second, because of the significant difference in the time to reach treatment temperatures, mixing pieces of different sizes in treatment charges will result in time related inefficiencies. Third, a 1-2 degree wet bulb depression heating was more time efficient than a 10 degree wet bulb depression. Finally, the use of wet bulb temperature with the MacClean equations allows the use of the heating tables published by Simpson (2004).

⁴ Simpson, W. T. 2001. Heating times for round and rectangular cross sections of wood in steam. Gen. Tech. Rep. FPL-RP-604. US DA Forest Service, Forest Products Laboratory, Madison, WI.

