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# Estimating heating times of frozen and nonfrozen logs using a graphic method

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## Notation

CD = core diameter (% of log diameter)
CDTE = a change in heating time, caused by a variation of the core diameter and/or the dimensionless temperature (%)
D = log diameter (m)
DE = diameter effect (%)
DT = dimensionless temperature (DT)
HT = heating time (h)
L = log length (m)
LDPE = a change in heating time, caused by a variation of the length vs. diameter ratio and/or the longitudinal-to-radial conductivity ratio (%)
MC = moisture content based on dry mass (%)
MCE = moisture content effect (%)
P = longitudinal-to-radial thermal diffusivity ratio (-)
SG = specific gravity based on dry mass and green volume (-)
SGE = specific gravity effect (%)
T = temperature (°C)

*Subscripts* :
f = final
o = initial
∞ = ambient

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## I - Introduction

Veneer logs are heat-conditioned in water or steam in order to soften the wood prior to peeling or slicing. Adequate heating improves both the quantity and the quality of veneer produced (Resch 1979), and maximizes the economic benefic (Sim et al. 1989 ; Steinhagen et al. 1989). When the optimum temperature for a given species is known, the question arising is how long a log with given dimensions should be exposed to heating in order to reach the target temperature. Accurate prediction of this time is particularly necessary when logs are initially frozen. The estimation of heating times can be done via simulation model LOGHEAT-2D (Khattabi 1992) based on the enthalpy method and finte-difference solution to the partial differential equation governing the heat-conditioning process (Khattabi and Steinhagen 1992). However, this model requires a computer use and calculations can be time-consuming, particularly for large-dimension logs or when the step size used in the finite-difference solution is small.

The purpose of this paper is to introduce a practical and easy-to-implement graphic method to compute heating time for peeler logs. The method uses charts and equations, and does not require any computing device. The charts and equations were built on data generated by LOGHEAT-2D. This method is more versatile than previously published graphic methods (MacLean 1946 ; Steinhagen et al. 1980 ; Steinhagen 1989). It covers logs of any length vs. diameter ratio, and accounts for temperature-dependent thermal properties and a variable longitudinal-to-radial thermal diffusivity ratio, for frozen and nonfrozen wood.

## II - Method

The method concerns the utilization of charts and simple equations to estimate the heating time (HT) to reach a target temperature in the cross-section and at some depth from the surface of a log. The charts and equations were based on data generated using the log-heating simulation model (Khattabi 1992a) for various log characteristics and heating conditions. Regression analysis of data obtained by varying each parameter in the model and holding others constant permitted us to construct relationships between the heating time and each parameter.

The parameters included in the simulation model are the target temperature ($T_f$), the target core diameter (CD), the bath temperature ($T_\infty$) and the log characteristics : diameter (D), length (L), moisture content (MC), specific gravity (SG), initial temperature ($T_o$) and the longitudinal-to-radial thermal diffusivity ratio (P).

Any change in one of these parameters affects the heating period. Some parameters have independent effects and some have combined effects with other parameters. The parameters with independent effects are (D), (SG), and (MC), and those with interdependent effects are, given in pairwise association, (L/D, P) and (CD, DT) where (DT) is the dimensionless temperature defined for nonfrozen logs as - $(T_\infty - T_f) / (T_\infty - T_0)$ and for frozen logs as $(T_\infty - T_f) / T_\infty$. For the sake of simplicity, we present the interdependent effects on charts and the independent effects by equations.

The combined effect of both the length vs. diameter ratio and the thermal diffusivity ratio (LDPE), is depicted in Figure 1. Similarly, the combined effect of the core diameter and the dimensionless temperature (CDTE) is presented in Figures 2 and 3 for frozen and nonfrozen logs, respectively.

The *diameter effect* (DE) is by far the most important among the independent effects and is given by :

**DE = (D/0,2)² ;** **(1)**

where D is in (m)

The *specific gravity effect* (SGE) :

**SGE (%) =**

**88 + 33,2 (SG) - 19 (SG)² - 100** **(2)**

The *moisture content effect* (MCE) :

**MCE (%) = 90 + 0,25 (MC) - 100,**

for nonfrozen logs **(3a)**

**MCE (%) = 78,5 + 0,56 (MC) - 100,**

for frozen logs **(3b)**

Given the same moisture content variation, the (MCE) is more important in frozen than in nonfrozen logs. This is explained by the fact that in addition to the MC influence on thermal properties and on wood density, as is the case for nonfrozen logs, it influences also the latent heat of thawing frozen logs.

The ranges of application of the relationships developed are :

DT = 0,05 to 0,4, CD = 0% to 40 % of log diameter, P = 1,5 to 3, SG = 0,4 to 1, MC = 40 to 120 % (MC > 120 % can also be considered without making significant errors), D >= 0,2 m and L/D >= 1.

The heating time, in hours, necessary to reach some target temperature in the cross-section and at some depth from the surface of a log, can be computed using the following relations :

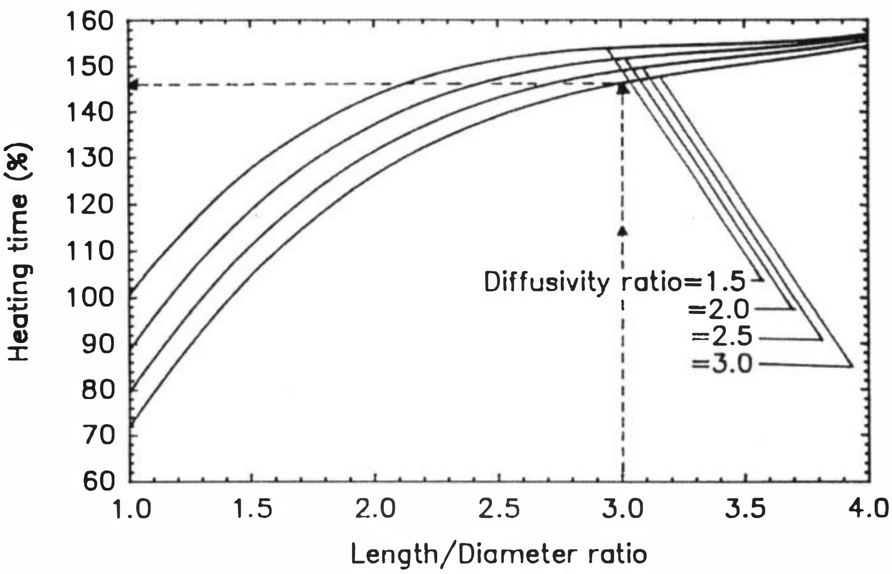


**Fig. 1 : Combined effect of the length/diameter ratio and the thermal diffusivity ratio on the heating time.**

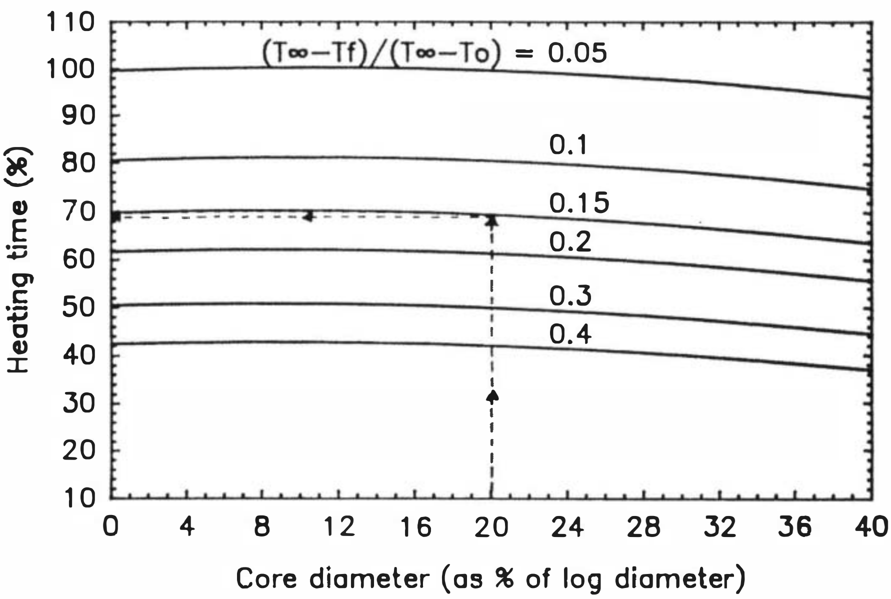


**Fig. 2 : Combined effect of the core diameter and the ratio : $(T_\infty - T_f) / (T_\infty - T_0)$ on the heating time of nonfrozen logs.**

HT =
7,5xDExCDTE(1 + SGE + MCE + LDPE)
for nonfrozen logs **(4)**

HT =
9,1xDExCDTE(1 + SGE + MCE + LDPE)
for frozen logs **(5)**

where the factors 7,5 and 9,1 are the reference heating times, in hours, for nonfrozen and frozen logs, respectively. These reference times were computed by the simulation model using the reference parameters which correspond to the lower values in the ranges of application of this method. The reference heating time for frozen logs was adjusted to correct for the initial temperature of logs which is not accounted for in the dimensionless temperature. Equation (5) can be applied only to completely thawed logs.

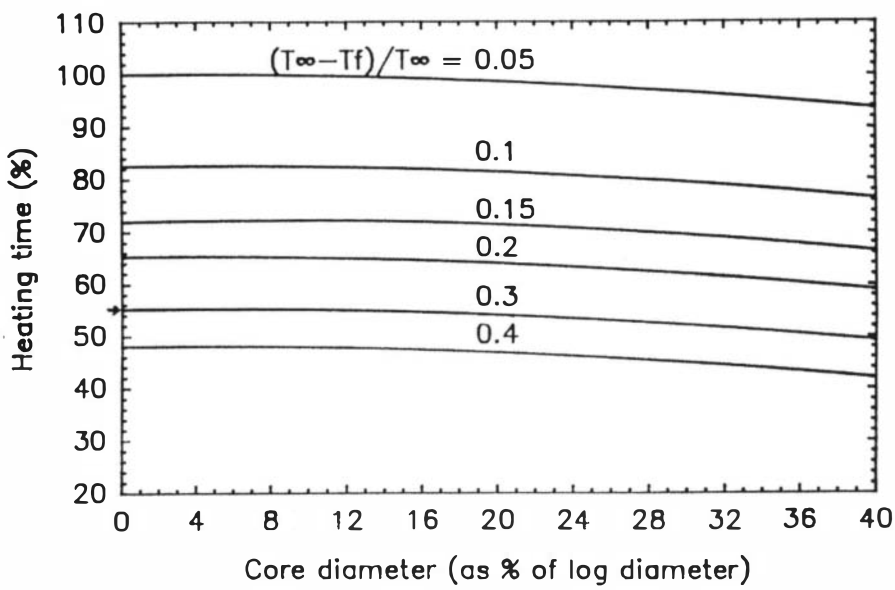


**Fig. 3 : Combined effect of the core diameter and the ratio : $(T_\infty - T_f) / T_\infty$ on the heating time of frozen logs.**

| | Log # 1 | Log # 2 |
|---|---|---|
| Diameter D (m) | 0,5 | 0,3 |
| Length L (m) | 1,5 | 0,78 |
| Therm. diffusivity ratio P (-) | 3 | 2,5 |
| Moisture content MC (%) | 50 | 80 |
| Specific gravity SG (-) | 0,7 | 0,6 |
| Core diameter CD (m) | 0,1 | 0 |
| Bath temperature $T_\infty$ (°C) | 80 | 60 |
| Initial temperature $T_0$ (°C) | 25 | -30 |
| Target temperature $T_f$ (°C) | 72 | 42 |
| L/D (-) | 3 | 2,6 |
| CD (% of D) | 20 | 0 |
| $(T_\infty - T_f) / (T_\infty - T_0)$ nonfrozen DT | 0,15 | |
| $(T_\infty - T) / T_\infty$ frozen DT | | 0,3 |
| CD & DT-effect CDTE (%) | 68,4 | 55,2 |
| SG-effect SGE (%) | 1,9 | 1,1 |
| MC-effect MCE (%) | 2,5 | 23,3 |
| L/D & P-effect LPDE (%) | 46 | 44,6 |
| D-effect DE (%) | 6,25 | 2,25 |
| HT predicted (h) | 48,2 | 19,1 |
| HT computed (h) | 50,5 | 20,3 |
| Discrepancy (%) | 4,5 | 5,9 |

**Table 1 : Examples of heating-time computation using the graphic method.**

All the parameters effects in Equations (4) and (5) are expressed in percent except the diameter effect which is a multiplication factor. CDTE is also a multiplication factor but expressed in (%). The remaining effects measure the additional percentage change in the reference heating time.

DE and SGE are computed using Equations (1) and (2), respectively. MCE is determined either from Equation (3a) or from Equation (3b) depending on the log state (nonfrozen or frozen). LDPE is obtained by subtracting 100 % from the value given by Figure 1. CDTE is determined directly from the Figures 2 and 3 for frozen and nonfrozen logs, respectively.

# III - Examples

As examples for using the graphs and the equations to estimate the heating time of bolts, let us consider two specimens : log # 1 (nonfrozen) and log # 2 (frozen). The characteristics of these logs, the heating conditions and the individual parameters effects are given in Table 1. The computation of the independent effects, i.e. DE, SGE and MCE, is straightforward using the corresponding equations. LDPE for log # 1 is equal to the value (146 %) indicated in Figure 1 (dashed line and arrows) minus 100 %. CDTE is determined directly from Figure 2 (dashed line and arrows) and is equal to 68,4 %. Similarly for log # 2, LDPE and CDTE are determined using Figures 1 and 3, respectively. The heating times are then determined using Equations (4) and (5) for log # 1 and log # 2, respectively, along with the computed parameters effects.

The same calculation procedure was used to predict the heating time in 24 tests (4 logs, 3 core diameters per log and 2 dimensionless temperatures per core diameter). The graphically predicted results are within +/- 7 % of those computed using the simulation model LOGHEAT-2D from which this method was derived. The method was also validated for long logs having more than four diameters length by comparing the predicted results using (L/D) = 4 in Figure 1 to a published one-dimensional method (Steinhagen 1989). It can be shown from Figure 1 that when L/D = 4, the percentage change in the heating time is approximately equal for all levels of (P) and can be considered constant and identical for all values of L/D greater or equal to 4.

# IV - Conclusion

A practical method, based on charts and simple equations, was developed to estimate heating times for frozen and nonfrozen logs, without computer use. Estimated heating times are in reasonable agreement (i.e., within +/- 7 % of deviation) with the predictions by computer model LOGHEAT-2D from which this method was derived.

**A. K.**

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## Résumé

**L'estimation des temps d'étuvage des grumes, gelées ou non gelées, par l'utilisation d'une méthode graphique**

*Les usines de placages/contreplaqués procèdent généralement à l'étuvage des grumes dans de l'eau chaude ou à la vapeur avant de les transformer. Le but de ce traitement thermique est de temporairement plastifier le bois afin de faciliter sa coupe d'une part, et d'améliorer le rendement matière et la qualité du placage d'autre part. En effet, un chauffage adéquat des grumes permet une amélioration de la qualité et de la quantité du placage obtenu et maximise le bénéfice économique de l'opération.*

*Quand la température optimale de transformation est connue pour une espèce donnée, le problème se posant alors est de déterminer avec une certaine exactitude le temps d'exposition au chauffage des grumes de dimensions données pour atteindre cette température optimale.*

*Dans cet article nous présentons une méthode graphique, pratique et facile à utiliser, permettant l'estimation des temps d'étuvage des grumes de déroulage. Cette méthode fait usage des courbes et d'équations dérivées des données générées par le modèle de simulation LOGHEAT-2D. Elle est valide pour les grumes, gelées ou non gelées, de tout diamètre et longueur.*

Mots-clés : Etuvage des grumes, méthode graphique

## Summary

**Estimating heating times of frozen and nonfrozen logs using a graphic method**

*Veneer logs are heat conditionned in water or steam in order to soften the wood prior to processing. Adequate heating improves both the quantity and the quality of veneer produced and maximizes the economic benefit. This paper presents a graphic method for estimating heating time necessary to reach target temperature at some internal point in the central cross section of a log. The method is valid for both frozen and nonfrozen logs, of any lenght vs. diameter ratio. The estimated results are in reasonable agreement with the predictions by computer model logheat-2D from which the graphic method was derived.*

Keywords : Log-heating, graphic method.