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Effect of Pre-steaming on the CCA Treatment of Spruce and Redwood Grown in Southern Sweden

Inverkan av ångning på CCA-impregnering av gran och furu från södra Sverige

by

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EFFECT OF PRE-STEAMING ON THE CCA TREATMENT OF SPRUCE AND REDWOOD GROWN IN SOUTHERN SWEDEN

Summary

The coast spruce (*Picea abies*) from southern Sweden can be satisfactorily impregnated by the oscillating pressure method (OPM) using a CCA preservative, only if felled during the winter. Steaming has a detrimental effect on the impregnation of these winter-felled logs. Penetration of preservative into logs felled during growth seasons is poor. In this case penetration is improved by steaming, but to an unsufficient degree.

Natural rounds of coast redwood (*Pinus sylvestris*) from southern Sweden did not treat well using the OPM, even when felled during the winter. If the logs were steamed and allowed to cool before impregnation, complete sapwood penetration could be achieved with a 6 hour OPM schedule, irrespective of felling season.

When redwood logs were steamed and conditioned to the maximum sapwood moisture ratio 60 % adequate results could be obtained by Bethell (vacuum-pressure) impregnation for a 2 hour pressure period. At this moisture ratio the concentration of the preservative solution is about 2.8 % Boliden K33.

If pre-treated by steaming and partial seasoning redwood boards can be successfully impregnated by the Bethell treatment. It is of particular interest that a substantial part of the heartwood is made penetrable by steaming.

INVERKAN AV ÅNGNING PÅ CCA IMPREGNERING AV GRAN OCH FURU FRÅN SÖDRA SVERIGE

Sammanfattning

Gran (Picea abies) växt vid kusten i södra Sverige kan tillfredsställande impregneras enligt växeltryckmetoden (OPM) med CCA impregneringsmedel endast om den fällts under vintern. På vinterfällt virke har ångning en försämrande inverkan på impregneringen. Hos virke fällt under årstider med botanisk aktivitet är inträngningen av impregneringsmedel dålig. Inträngningen förbättras i dessa fall genom ångning, men i otillräcklig grad.

Rundvirke av furu (Pinus sylvestris) växt vid kusten i södra Sverige går ej bra att impregnera med OPM, ej ens om den fällts under vintern. Om stockarna ångats och fått kallna före impregneringen, erhölls fullständig inträngning av splinten med 6 timmars OPM program oberoende av årstid för fällningen.

Om furustockarna ångats och fått partiellt torka till maximum 60 % fuktkvot i splinten erhölls fullgott resultat med Bethell-impregnering (vakuum-tryck) med 2 timmars tryckperiod. Vid denna fuktkvot är lämplig koncentration hos impregneringslösningen 2.8 % Boliden K33.

Med ångning och partiell torkning kan nysågade furubräder framgångsrikt impregneras enligt Bethell. Av speciellt intresse är att ångningen gjort en betydande del av kärnveden impregneringsbar.

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EFFECT OF PRE-STEAMING ON CCA TREATMENT OF SPRUCE AND REDWOOD GROWN IN SOUTHERN SWEDEN

Sven-Eric Dahlgren *

1. Introduction

Steaming of green wood is used in New Zealand with great success as a pre-treatment to aid preservation. Its main application is with Radiata pine and Corsican pine, but it is also used for Ponderosa pine, Strobus, Rimu amongst others. Felling, transport, barking, sawing if applicable, and steaming are normally carried out in unbroken succession all the year around, followed by conditioning (cooling) and preservation by the oscillating pressure method, OPM, using CCA preservative. The length of the OPM treatment varies between 1½ and 8 hours depending on wood species, dimension and time of year, according to practical experience. A time lapse of three to four days between felling and preservation is common. To some extent steaming is also used in the United States in connection with preservation.

With this background in mind it was considered to be of interest to evaluate the effect of steaming on preservation of the two most important Scandinavian wood species European spruce (*Picea abies*) and European redwood (*Pinus sylvestris*).

2. General background about steam conditioning

2.1 Heat transfer in wood and steam conditioning

Extensive investigations on the heat transfer in round timber and sawn lumber during steaming were carried out by MacLean in the early 1930's (1, 2) and the results were brought together in a handbook (3). All data were given in non-metric units and

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presented in a fairly inconvenient way. Applying these basic heat transfer equations for rounds and neglecting the end heat transfer, a computer program has been written using metric units (programming and computer work carried out by Hans Alsholm). See Appendix 1. The calculations assume the initial wood temperature to be 16°C and the thermal diffucivity of wood to be 0.00160 cm^2/sec.

Within the actual working range the correction in steaming time for deviating initial wood temperature is approximately 1 % per °C. The steaming time is inversely proportional to the thermal diffucivity, thus

$$t_{corr} = t_{tab} \cdot \frac{0.00160}{a}$$

where t_{corr} = steaming time for wood with thermal diffucivity "a"

t_{tab} = tabulated steaming time for wood with thermal diffucivity 0.00160

$a = \frac{\lambda}{\rho \; c_p}$ = thermal diffucivity

ρ = density

c_p = specific heat capacity at constant pressure

λ = thermal conductivity

Nomenclature and symbols used are according to ISO/R 31 and Swedish Standard SIS 01 61 50.

MacLean's experiments showed a linear relationship between the bulk density (formerly: specific gravity) of oven-dry wood (105°C) and the thermal diffucivity. This relationship is given in Figure 1 with steam as heating medium, after conversion to metric units.

Figures 2 - 7 are diagrams for estimation of the time to reach a certain temperature at a certain depth from the surface of rounds as a function of the diameter. Two steam temperatures have been chosen 120 and 125°C. In practice it takes a certain time to reach the steaming temperature. Half this time may be deducted from the calculated steaming time.

The heating rate is 2.25 to 2.75 times faster in the longitudinal direction of a piece of wood than in the radial or tangential directions. In experimental work therefore the length of a specimen must be at least 6 times its radius to eliminate end effects.

2.2 Existing specifications for steaming

Steam conditioning must on one hand be sufficient to improve the penetrability of the preservative to a desired extent, but on the other hand not so severe that it seriously damages the wood or impairs its mechanical strength. The compromise between these demands differs for different wood species. AWPA Standards (4) stipulate that steaming is not permitted in the treatment of Douglas fir poles and piles, but for other applications of this species allow a maximum steaming temperature of 116°C and maximum steaming time of 6 hours. For Southern pine a maximum steaming temperature of 119°C and a time of 17 hours is stipulated with lumber and timber or 20 hours with poles and piles. With both species, the maximum temperature must not be reached in less than 1 hour. The heating rate has to be slow enough to minimise formation of heartwood cracks, which are caused by different thermal expansion between the surface and the core.

In New Zealand Timber Preservation Authority (5) process specification P9 a steaming temperature 127°C is allowed for natural rounds of Radiata pine and 121°C for natural rounds of Corsican pine. For sawn timber of the two species 127°C is allowed. No heating rate limits are given. Excessive steaming must be avoided as it will seriously damage the wood. A general principle is that steaming should be as mild as is consistent with good absorption and penetration of preservative.

2.3 Vacuum treatment after steaming

If a vacuum is applied after steaming, the temperature of the moisture within the wood is considerably above the boiling point of water at the reduced pressure. Water vapor is therefore formed within the wood, which pushes off part of the moisture. Vacuum also speeds up the evaporation of water. More moisture is therefore removed during the vacuum period than corresponds to the heat content of the wood. A further consequence is that cooling is speeded up. Moisture removal by vacuum after steaming means removal of some sap from the system, which could possibly create an environmental pollution problem. Most of the moisture removal takes place during the first hour of vacuum. There seems to be little, if any, advantage in continuing the vacuum for more than 2 hours (6).

Vacuum after steaming is not included in the New Zealand specification, but the pressure must be released as rapidly as possible and the wood left to cool under open rain-shedding covers for at least 24 hours. Extending the conditioning to more than 24 hours improves the preservation. In any event, it is concial that the wood is conditioned after steaming for a sufficiently long time to let it cool.

3. Preparation of specimens

Natural rounds of spruce grown at Kulla Gunnarstorp north of Helsingborg and redwood grown at Vegeholm near Engelholm in southern Sweden were used in the experiments. Sawn redwood was obtained from Suntetorp near Skövde. The timbers were transported to Boliden's pilot plant immediately after felling and cut into 70 cm long specimens, which were end sealed with asphalt epoxy. The mean diameter and the mean sapwood depth were estimated on each specimen, the latter from the appearance of the fresh cross-cuts in spruce and with heartwood reagent for pine. Three discs were taken from each tree for moisture and oven-dry bulk density determinations. The end-sealing was damaged during steaming. After steaming, therefore, the specimens were cut to 60 cm length and a new end-sealing carried out. The resulting discs were used for moisture determination. Peeling was done immediately before steaming and in the case of unsteamed controls immediately before preservation. Specimens with an estimated steaming time within ± 15 minutes were steamed in the same charge to limit the number of runs.

After steaming the specimens were conditioned in open air for three days and then kept in closed plastic bags until the preservation could be carried out.

After preservation the specimens were left for fixation for one week at room temperature before discs were cut in the center of each specimen for evaluation. These discs were stained with copper reagent.

A solution of the CCA preservative Boliden K33 was used in all experiments, and the specimens were all numbered from the butt end.

4. Experiments with spruce

4.1 Trees felled in April

A first series of experiments was carried out on two spruce trees felled in April. The design was a fractional factorial experiment with five factors at two levels in sixteen observations.

Factor		Levels	
A	Steam temperature	110	120°C
B	Temperature at sapwood-heartwood interface	85	95°C
C	Vacuum time after steaming	none	1 hour
D	Tree	I	II
E	Part of tree	lower half	upper half

The time to reach the top temperature was chosen to 1 hour. Further details are given in table 1.
All specimens were treated in the same charge with a standard 20 hour OPM schedule and 10 minutes of initial pressure. The temperature of the 2 % Boliden K33 solution was kept at 14-16°C during treatment.

The two trees were very different in character. The width of the sapwood year rings differed by a factor about 4, tree II being very slowly grown. This explains the great difference in original sapwood moisture ratio. The vacuum after steaming had only a minor influence on the sapwood moisture ratio measured after conditioning for three days in the open air. All steamed specimens showed radial heartwood cracks, but not the unsteamed controls. The heating rate had therefore probably been too high.

When evaluating the results of the OPM treatment the preservative penetration was considered as well as the intensity of the copper staining after preparation with copper reagent. It was not possible to express this in numerical values and a subjective evaluation had to be accepted. Compared with the unsteamed references, there was a remarkable improvement in the penetration depth due to steaming. There were only minor differences in the penetration depth between specimens with and without vacuum treatment after the steaming, but with vacuum the intensity of the copper staining was considerably weaker. The effect of vacuum after steaming was thus negative. An increase in the temperature at the sapwood-heartwood interface improved the intensity of the copper staining, while an increase in the steam temperature seemed to be less important.

As the longitudinal heating rate is higher than the radial and tangential ones, discs were also cut 15 cm from the end of each specimen, where a higher interface temperature was achieved than in the centrally taken discs. The copper staining intensity was considerably better and more even on the end discs than on the central discs. A higher temperature was therefore considered beneficial.

Although steaming considerably improved the penetration, it was considered that the preservation had not been fully successful.

4.2 Trees felled in May, August and January

The experimental design was the same at all three felling seasons - May, August and January.

Factors		Levels	
Temperature at sapwood-heartwood interface, °C	95	100	105
Tree	I	II	III
Part of tree	lower half		upper half

Constant factors:	steam temperature	120°C
	vacuum after steaming	none
	time to reach top temp	1½ hour

The OPM schedule was the same as in the April experiment. Details of specimens and treatment are given in the tables 2, 3 and 4.

The results were similar for the trees felled in May and August and are therefore discussed together. In the unsteamed controls only a rather thin surface layer was penetrated. With steaming there was a strongly stained outer zone, slightly deeper than on the unsteamed ones and a weakly stained inner zone. Although the steaming had a positive effect, the penetration was far from acceptable. The sapwood-heartwood interface temperature did not seem to have any effect. Most of the steamed specimens had radial heartwood cracks in the centre, but to a lesser degree than in the April trials. The slower heating-up had thus been beneficial.

The trees felled in January behaved completely differently. In these cases only the unsteamed references were satisfactorily penetrated and the steamed ones were not acceptable. The penetration depth in the unsteamed specimens was less for tree III than for the other two trees. This is explained by very narrow annual rings about 0.6-0.7 mm in tree III. About 18 annual rings were penetrated in this tree. The penetrated part of the unsteamed specimens was analyzed by X-ray technique (7).

Tree	Part	Cu %	Cr %	As %	Penetration depth, mm
I	outer third	0.71	1.07	1.50	
	middle third	0.78	0.72	1.21	23-30
	inner third	0.54	0.42	0.69	
II	outer third	0.61	0.96	1.38	
	middle third	0.72	0.60	1.04	18-25
	inner third	0.44	0.37	0.59	
III	the whole section	0.61	0.78	1.17	10-12

The preservative content is above the specification for normal use, which is 0.52, 0.39 and 0.26 % As in the outer, middle and inner third, resp.

4.3 Conclusions about spruce

The results indicate that coast spruce from southern Sweden can be satisfactorily impregnated by the OPM method using CCA preservative only if felled during the winter. On winter-felled logs steaming has a detrimental effect on the impregnation.

On logs felled during seasons of botanic activity penetration of preservative is poor. The penetration is improved by steaming but to an insufficient extent.

In Switzerland and southern Germany there are several plants treating spruce according to the oscillating pressure method. Only winter felled spruce is used. In Switzerland the logs are during the winter transported to the treating plant, piled and covered by shavings to maintain the original condition as far as possible until treatment.

5. Experiments with natural rounds of redwood

5.1 Trees felled in May

The experiments were divided into three series.

In Series 1 an OPM treatment with full vacuum using unsteamed specimens was carried out as a control. Data about the specimens are given in table 5. The length of the OPM program was increased from 8 to 16 and 22 hours without any improvement in the sapwood penetration. Only about one third of the sapwood was penetrated.

In Series 2 an OPM treatment with reduced vacuum (8, 9) using unsteamed specimens was applied. During the first third of the treating time the vacuum level was about 30 %, during the second third 60 % and during the last third maximum obtainable vacuum was used. The length of the OPM program was increased from 8 to 16 and 22 hours without any improvement in sapwood penetration. The penetration was in fact slightly less than in Series 1.

In Series 3 an OPM treatment with full vacuum was applied on steamed specimens. The steaming conditions were:

steam temperature	120°C
temperature at sapwood-heartwood interface	100°C
vacuum after steaming	none
heating-up time	1½ hours
conditioning in air after steaming	3 days

The OPM program length was decreased from 8 to 6 and 4 hours. Almost complete sapwood penetration was obtained. There was a tendency towards less penetration at 4 hours treatment than at 6 and 8 hours treatment. Possibly slightly more intense steaming could be beneficial. The results show that with steaming redwood felled in summer can be satisfactorily penetrated with an OPM schedule of fairly short length. The results are in accordance with the New Zealand experience on Pinus spp.

5.2 Trees felled in August

The steaming time was increased over series 3 of the trees felled in May. Three trees were used. The steaming conditions were:

Steam temperature	120°C
Temperature at sapwood-heartwood interface	105°C
Heating-up time	1½ hour
Conditioning in air after steaming	3 days

Data about the specimens are given in table 6.

Design of experiment

Factor	Level
A. vacuum after steaming	1. none
	2. 1 hour
B. type of impregnation	1. OPM with full vacuum, 4 h
	2. Bethell *
	a. pressure time 1 hour
	b. pressure time 2 hours

* Initial vacuum 30 min, final vacuum 10 min

The moisture ratio of the steamed, conditioned specimens was considerably higher than in air-seasoned wood normally used for Bethell treatment. To compensate for this the solution strength in these trials was increased to 2.3 % Boliden K33 from 2.0 % in the earlier trials.

The 4 hour OPM schedule was not quite acceptable as complete sapwood penetration was not achieved. Almost the same penetration pattern was obtained with the Bethell treatment using 1 hour pressure, while with 2 hours pressure the penetration was improved and considered acceptable. There was hardly any effect of vacuum after steaming on the penetration pattern.

Cross sections of the specimens treated with Bethell using 2 hours pressure were analyzed, see table 7. The outer, middle and inner third of the sapwood were analyzed separately. We find that the preservative content is below the specification for normal use. A higher solution concentration, than used in the experiments, is needed to compensate for the actual moisture ratio. A concentration about 2.8 % Boliden K33 is expected.

The results show that Bethell treatment is a potential alternative to OPM treatment for steamed conditioned green redwood.

5.3 Trees felled in January

The steaming conditions were the same as for the trees felled in August. The concentration of the preservative solution was chosen to be 2.8 % Boliden K33. Three trees were used in the trials. Data for the specimens are given in table 8.

5.31 OPM treatment

Unsteamed specimens were OPM-impregnated, using a standard OPM programme with full vacuum to give reference data. A 16 hour OPM schedule gave unacceptable preservative penetration of the sapwood. Increasing the schedule to 22 hours improved penetration, but complete sapwood penetration was not achieved. A possible explanation for this insufficient penetration could be the unusual mild winter of 1974-1975 having hardly any frost.

A 4 hour OPM schedule on steamed specimens, conditioned for 3 days after steaming, gave better preservative penetration than did the unsteamed specimens. Increasing the schedule to 6 hours improved the penetration pattern although the copper staining of the sapwood closest to the heartwood was weak.

5.32 Bethell treatment

The conditions for the Bethell treatment were:

initial vacuum 95 %	30 minutes
pressure 0.9 MPa	2 hours
final vacuum	10 minutes

The pressure period was chosen from the experience gained under 5.2. Two factors were studied:

the length of the conditioning period being 3, 10 and 17 days
the effect of 1 hour vacuum after steaming and before conditioning.

After 3 days conditioning the average moisture ratio in the sapwood before impregnation was 68 % for the specimens having vacuum treatment after steaming; this compares with 85 % for those not subject to vacuum treatment. The penetration was acceptable in trees 1 and 3, but some sapwood in tree 2 was not penetrated.

With 10 days conditioning the average moisture ratio before impregnation was 62 % with vacuum treatment against 77 % without. Complete sapwood penetration was achieved in all trees with vacuum treatment, but in tree 2 without vacuum treatment the penetration was not quite complete. The preservative distribution was better than that achieved with 3 days conditioning. In table 9 analyses are given of the outer, middle and inner third of the sapwood of specimens having vacuum treatment after steaming and 10 days conditioning. The inner third of tree 2 had slightly below, and the inner third of tree 3 had about half, the content of As specified for normal use (see 4.2).

17 days conditioning was examined only for specimens not subjected to vacuum treatment after steaming. The average sapwood moisture ratio was 55 %. Preservative penetration was acceptable in all trees and, as seen from table 9, the preservative concentration was, in every case, above that specified for normal use.

5.4 Conclusions concerning natural rounds of redwood

Unsteamed natural rounds of redwood did not achieve acceptable preservative penetration with a 2 hour OPM schedule, even if felled during the winter. If steamed and allowed to cool complete preservative penetration could be achieved with a 6 hour OPM schedule. With steaming the felling season made no difference to the impregnation.

When the rounds were steamed and conditioned to the maximum moisture ratio 60 % in the sapwood, adequate results were obtained by vacuum-pressure (Bethell) impregnation with a 2 hour pressure period. Applying a vacuum period immediately after the steaming the conditioning reduces the time taken to reach the required moisture ratio. At this moisture ratio the concentration of the preservative solution should be about 2.8 % Boliden K33 for normal use. The solution concentration has to be balanced against the moisture ratio.

To avoid severe heartwood cracking the heating-up time at steaming shall be at least 1½ hour. An even slower heating rate would probably be beneficial.

At first sight, Bethell impregnation of steamed and partially seasoned redwood seems to be a more promising alternative to OPM impregnation since it is faster and any common vacuum pressure unit may be used. An OPM unit is more complicated and thus considerably more expensive.

Independently a similar investigation has been carried out in New Zealand by McQuire (10) on the Bethell treatment of steamed and partially seasoned Corsican pine and Radiata pine posts. The general conclusions were the same as those of the present investigation.

6. Experiments on the Bethell treatment of freshly sawn redwood after steaming

With the promising results of Bethell impregnation of steamed natural rounds of redwood in mind, experiments were carried out with sawn green redwood.

Two redwood trees were felled early August 1974 at Suntetorp near Skövde, immediately sawn,wrapped in plastic sheet and transported to the laboratory. Any remaining bark was removed. The boards were cut into three equal lengths and samples for moisture ratio determination of the whole cross section were taken. The end surfaces were sealed with asphalt epoxy.

Cross section of the boards:

	Tree I	Tree II
Board 1	28 x 200 mm **	22 x 157 mm **
2	28 x 200 mm	28 x 157 mm
3	39 x 200 mm	40 x 157 mm
4	39 x 200 mm	40 x 157 mm
5	20 x 200 mm	28 x 157 mm **
6	28 x 200 mm **	23 x * mm **

* not trimmed ** surface boards

The effect of partial seasoning before steaming was studied as follows:

Trial A. The butt-end third was steamed immediately after preparation.

Trial B. The middle third was stacked on sticks and air dried indoors for 7 days before steaming.

Trial C. The top third was stacked on sticks and air dried indoors for 14 days before steaming.

Steaming was carried out according to New Zealand specification P9 for Radiata and Corsican pine boards.

Pre-treatment:

Steam temperature 127°C, full steam pressure applied directly. Steaming time 90 minutes for boards 3 and 4 and 60 minutes for the other boards.
No vacuum treatment was applied after the steaming.
Conditioning was effected by stacking on sticks, indoors, for the three days between steaming and impregnation.

Impregnation: initial vacuum 95 % 30 minutes
pressure 0.9 MPa 2 hours
final vacuum none
solution 3.1 % Boliden K33

Treatment data are given in table 10.

The salt retention was well above the specification in all three trials. This means that the chosen preservative concentration was unnecessarily high.

Complete sapwood penetration was achieved only in trial C. The penetration was better in trial B than in trial A. Of particular interest was the observation that in trial C a substantial part of the heartwood was penetrated. No heartwood cracks appeared.

6.1 Conclusions about sawn redwood

The average moisture ratio of the whole section was 72 % in trial A, 55 % in trial B and 40 % in trial C. That in this case a lower moisture ratio limit was found for acceptable penetration than with natural rounds is at least partly explained by the fact that (i) part of the sapwood is removed by sawing and that (ii) it relates to the whole cross section after sawing and not only to the sapwood, as in the previous trials. Whether the moisture ratio limit is affected when the partially seasoning takes place - before or after steaming - remains to be investigated.

Steaming of several wood species has been reported to increase the drying rate (11). Although there are no data available for redwood, it is expected that it behaves similarily. Since steaming "opens up" the structure enabling more efficient penetration of preservative solution, the increased permeability must also increase the drying rate.

The fact that steaming makes the heartwood penetrable may be of special interest to preservation with fire retardents, since this application is currently limited to the use of pure sapwood. This topic warrants further investigation.

7. Remarks

The present investigation is only of a preliminary nature. Further trials on a larger scale are needed before recommendations to impregnation plants can be given. It is the author's wish that the present investigation will act as a basis for further studies, since he is now leaving the wood preservation field.

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Table 1. Specimen, steaming and OPM data on spruce felled in April, 1973

Tree-specimen No	Sapwood moisture ratio, %	Bulk density, oven-dry g/cm^3	Thermal diffucivity cm^2/sec x 10^5	Mean diameter, mm	Mean sapwood depth, mm	Steam temperature, ^{o}C	Temperature at sapwood-heartwood interface, ^{o}C	Calculated corr. steaming time, h	Vacuum after steaming, h	Specimen weight, kg: before steaming	Specimen weight, kg: after steaming	Specimen weight, kg: after steaming and conditioning	Sapwood moisture ratio after steaming and conditioning, %	Specimen weight, kg: before OPM	Specimen weight, kg: after OPM
I-1				192	53	110	85	3.35	none	17.4	16.8	15.5	84	13.45	14.65
I-2	131	0.49	197	190	45	120	95	3.15	none	16.9	16.3	15.1	87	13.35	14.30
I-3				185	42	120	85	2.25	1	16.6	15.2	14.2	80	12.30	13.60
I-4				182	45	110	95	3.75	1	16.2	15.0	13.7	80	11.95	12.80
I-5				180	45	-	-	-	-	-	-	-	149 x)	15.00	16.45
I-6	149	0.46	207	176	44	120	85	2.10	none	14.2	13.7	12.4	109	10.90	11.60
I-7				168	42	110	95	3.00	none	13.8	13.4	12.1	103	10.40	11.35
I-8				164	42	110	85	2.15	1	13.3	12.4	11.4	109	9.65	10.40
I-9	152	0.45	210	156	42	120	95	2.20	1	11.8	10.6	9.7	87	8.40	9.35
II-1				157	42	120	85	2.15	none	12.2	11.8	10.7	45	9.35	10.55
II-2	86	0.59	166	148	40	110	95	3.10	none	10.1	9.9	8.8	46	7.75	8.95
II-3				142	38	110	85	2.05	1	9.2	8.6	7.8	42	6.70	8.35
II-4				136	37	120	95	1.75	1	8.4	7.6	7.0	43	6.25	7.65
II-5				133	35	-	-	-	-	-	-	-	80 x)	8.25	9.15
II-6	80	0.60	160	130	34	110	85	1.80	none	7.8	7.5	6.7	45	5.80	7.15
II-7				128	33	120	95	2.00	none	7.8	7.6	6.9	48	5.90	7.25
II-8				127	33	120	85	1.40	1	7.4	6.8	6.2	42	5.30	6.55
II-9	85	0.60	160	126	34	110	95	2.30	1	7.3	6.8	6.1	44	5.10	6.65

Specimens are numbered from the butt end.

x) unsteamed control specimen

Table 2. Specimen and treatment data on spruce trees felled in May, 1973. Steam temperature 120^{o}C in all experiments. Time to reach full steam pressure 1½ hour.

Tree-specimen No	Sapwood moisture ratio %	Bulk density, oven-dry g/cm^3	Thermal diffusivity cm^2/sec x 10^5	Mean diameter, mm	Mean sapwood depth, mm	Temperature at sapwood-heartwood interface, ^{o}C	Calculated corr steaming time, h	Steaming charge	Specimen weight, kg			Sapwood moisture ratio after steaming and conditioning, %	Specimen weight, kg	
									before steaming	after steaming	after steaming and conditioning		before OPM	after OPM
I-1				155	33	100	3.15	A	15.05	14.65	13.25	70	10.40	12.25
I-2	104	0.58	169	152	32	95	2.20	B	13.25	12.85	11.60	66	8.85	10.65
I-3				148	32	105	2.95	A	12.45	12.05	10.70	61	8.40	10.00
I-4	104	0.59	166	148	33	-	-	*	-	-	-	104	9.70	10.40
I-5				145	33	105	2.90	A	11.55	11.20	9.90	61	7.70	9.35
I-6	114	0.56	175	140	35	95	2.05	C	10.85	10.50	9.05	50	7.15	9.00
I-7				136	36	100	2.50	B	10.60	10.25	9.15	70	6.85	8.40
II-1				178	45	100	4.10	D	19.00	18.50	16.20	82	12.30	14.90
II-2	132	0.52	188	174	45	95	3.00	A	18.30	17.70	16.10	91	12.40	14.40
II-3				168	45	105	3.65	D	17.30	16.85	14.60	86	11.45	13.85
II-4	126	0.51	191	162	47	-	-	*	-	-	-	126	14.05	15.20
II-5				160	47	105	2.95	A	16.50	15.90	14.40	93	11.35	13.25
II-6	142	0.50	194	156	48	95	2.25	B	15.65	15.25	13.80	101	10.65	12.40
II-7				152	47	100	2.80	A	14.60	14.20	12.80	107	10.40	12.00
III-1				174	30	100	3.05	A	17.05	16.60	14.90	78	12.00	13.95
III-2	125	0.49	197	166	30	95	2.15	B	14.60	14.30	12.90	83	10.05	11.90
III-3				158	30	105	2.65	A	13.65	13.35	12.00	71	9.15	11.15
III-4	120	0.50	194	152	30	-	-	*	-	-	-	120	10.75	11.20
III-5				148	29	105	2.40	B	12.60	12.25	11.05	78	8.30	10.35
III-6	112	0.49	197	145	27	95	1.70	C	12.05	11.70	10.10	61	7.80	9.65
III-7				140	27	100	2.05	C	11.50	11.15	9.60	61	7.45	9.35

Specimens are numbered from the butt end

* unsteamed control specimens

Steaming charge A = 3.57 h, B = 2.98 h, C = 2.61 h and D = 4.50 h

Table 3. Specimen and treatment data on spruce trees felled in August, 1973.
Steam temperature 120 °C in all experiments. Time to reach full steam pressure 1½ hour.

Tree-specimen No	Sapwood moisture ratio %	Bulk density, oven-dry g/cm³	Thermal diffuctivity cm²/sec x 10⁵	Mean diameter, mm	Mean sapwood depth, mm	Temperature at sapwood-heartwood interface, °C	Calculated corr steaming time, h	Steaming charge	Specimen weight, kg: before steaming	after steaming	after steaming and conditioning	Sapwood moisture ratio after steaming and conditioning, %	Specimen weight, kg: before OPM	after OPM
I-1	169	0.42	220	160	36	100	2.50	B	11.4	11.0	9.5	84	8.4	10.1
I-2				156	38	95	1.80	B	11.0	10.5	9.1	88	8.0	9.8
I-3	167	0.39	229	154	38	105	2.30	B	10.8	10.4	9.1	91	7.9	9.5
I-4				147	37	-	-	*				170	9.9	10.7
I-5	175	0.39	229	142	34	105	1.90	B	9.5	9.1	7.9	102	6.8	8.2
I-6				136	35	95	1.40	C	8.6	8.3	7.1	107	6.2	7.5
I-7	169	0.41	223	132	36	100	1.80	B	8.2	7.8	6.8	103	5.9	7.2
II-1	116	0.50	194	168	28	100	2.60	A	11.5	11.1	9.8	61	8.4	10.2
II-2				166	30	95	2.00	B	11.3	11.0	9.5	58	8.2	10.1
II-3	107	0.52	198	164	31	105	2.80	A	10.7	10.4	9.1	58	7.9	9.7
II-4				160	35	-	-	*				115	10.6	11.6
II-5	124	0.52	188	158	35	105	2.80	A	10.1	9.7	8.5	63	7.3	9.1
II-6				154	36	95	1.90	B	9.9	9.5	8.3	67	7.0	8.6
II-7	117	0.48	201	151	36	100	2.50	A	9.6	9.2	8.0	62	6.8	8.6
III-1	124	0.49	197	144	31	100	2.20	B	9.4	9.2	8.1	77	7.1	8.9
III-2				141	31	95	1.50	C	9.0	8.8	7.9	67	6.9	8.2
III-3	137	0.49	197	134	32	105	1.90	B	8.5	8.2	7.2	74	6.2	7.7
III-4				128	30	-	-	*				135	7.8	8.9
III-5	130	0.47	208	124	32	105	1.70	C	7.2	7.0	6.2	70	5.3	6.7
III-6				122	32	95	1.20	C	7.0	6.8	5.9	72	5.1	6.5
III-7	140	0.47	208	118	30	100	1.50	C	6.5	6.3	5.4	70	4.7	6.1

Specimens are numbered from the butt end.

* unsteamed control specimens

Steaming charge A = 3.30 h, B = 2.80 h, C = 2.20 h

Table 4. Specimen and treatment data on spruce trees felled in January, 1974. Steam temperature 120°C in all experiments. Time to reach full steam pressure 1½ hour.

Tree-specimen No	Sapwood moisture ratio %	Bulk density, oven-dry g/cm^3	Thermal diffusivity $cm^2/sec \times 10^5$	Mean diameter, mm	Mean sapwood depth, mm	Temperature at sapwood-heartwood interface, °C	Calculated corr. steaming time, h	Steaming charge	Specimen weight, kg: before steaming	Specimen weight, kg: after steaming	Specimen weight, kg: after steaming and conditioning	Sapwood moisture ratio after steaming and conditioning, %	Specimen weight, kg: before OPM	Specimen weight, kg: after OPM
I-1	136	0.493	196	166	45	100	2.9	D	12.75	12.20	11.05	100	10.20	12.40
I-2				162	48	95	2.6	C	12.35	11.85	10.65		9.80	11.85
I-3	144	0.493	196	159	49	105	3.4	D	11.80	11.25	10.20	111	9.45	11.20
I-4				154	50	-	-	*					11.00	11.85
I-5	147	0.467	210	150	48	105	2.8	D	10.70	10.15	9.15	112	8.40	9.90
I-6				146	47	95	2.1	C	10.25	9.80	8.65		7.90	9.65
I-7	157	0.466	210	139	47	100	2.1	C	9.55	9.05	8.05	116	7.45	8.85
II-1	130	0.570	172	144	22	100	1.8	B	9.20	8.90	8.05	70	7.40	8.90
II-2				139	20	95	1.3	A	8.85	8.65	7.70		7.10	8.50
II-3	122	0.575	170	134	20	105	1.9	B	8.15	7.80	7.00	74	6.40	7.85
II-4				128	18	-	-	*					7.15	7.85
II-5	119	0.557	177	127	22	105	1.8	B	7.30	7.00	6.15	74	5.60	7.00
II-6				125	25	95	1.4	A	7.00	6.65	5.85		5.35	6.65
II-7	123	0.550	179	124	27	100	1.6	B	6.60	6.40	5.55	64	5.05	6.35
III-1	122	0.512	190	138	23	100	1.6	B	7.20	7.00	6.15	85	5.50	7.25
III-2				130	20	95	1.1	A	6.60	6.45	5.65		5.15	6.65
III-3	101	0.547	180	127	19	105	1.5	B	6.00	5.90	5.10	64	4.65	6.05
III-4				125	19	-	-	*					5.15	5.75
III-5	108	0.550	178	118	19	105	1.4	A	5.25	5.05	4.35	75	3.95	5.15
III-6				112	19	95	0.8	A	4.85	4.70	4.00		3.65	4.85
III-7	92	0.567	173	112	19	100	1.1	A	4.75	4.60	3.95	49	3.50	4.75

Specimens are numbered from the butt end * unsteamed control specimens

Steaming charge A = 2.05 h, B = 2.65 h, C = 3.35 h, D = 4.00 h

Table 5. Specimen and treatment data on redwood trees felled in May, 1974. Steam temperature 120°C. Time to reach full steam pressure 1½ h.

Series	Tree-specimen No	Moisture ratio before OPM, %	Sapwood depth, mm	Mean diameter, mm	Weight in kg after: Peeling	Steaming	Conditioning	OPM	Calculated corr steaming time, h	OPM treatment, h	Retention kg solution/m^3
1	I-1	102	60	168	9.80	-	-	10.65	-	8	80
	II-4	108	42	133	5.85	-	-	6.35	-	8	75
	III-7	107	40	142	7.55	-	-	8.15	-	8	75
	I-4	109	55	143	7.20	-	-	8.05	-	16	105
	II-7	109	35	124	4.90	-	-	5.40	-	16	85
	III-1	106	55	178	12.45	-	-	13.60	-	16	95
	I-3	109	55	148	7.75	-	-	8.80	-	22	70
	II-6	114	40	124	5.30	-	-	5.95	-	22	110
	III-9	120	40	137	7.05	-	-	8.00	-	22	125
2	I-7	106	45	135	6.00	-	-	6.55	-	8	95
	II-1	97	45	154	8.45	-	-	9.15	-	8	75
	III-4	110	45	154	8.50	-	-	9.15	-	8	70
	I-9	117	50	126	5.05	-	-	5.75	-	16	115
	II-3	108	42	133	6.15	-	-	6.80	-	16	95
	III-6	117	40	148	7.80	-	-	8.65	-	16	100
	I-6	112	45	137	6.60	-	-	7.45	-	22	115
	II-9	120	35	116	4.50	-	-	5.05	-	22	105
	III-3	110	50	157	9.40	-	-	10.30	-	22	95
3	I-8	62	45	132	8.10	7.60	6.35	8.70	3.67	8	245
	II-2	62	45	141	10.00	9.45	8.25	10.50	3.67	8	205
	III-5	80	40	155	11.40	10.65	9.45	12.60	3.67	8	240
	I-5	73	50	141	9.80	9.15	8.00	10.50	3.67	6	230
	II-8	59	35	116	6.65	6.15	5.05	7.00	2.83	6	265
	III-2	78	55	168	14.10	13.60	12.25	15.85	4.50	6	230
	I-2	71	60	166	11.60	11.15	9.85	12.15	4.50	4	150
	II-5	67	40	123	7.70	7.15	6.10	7.45	2.83	4	165
	III-8	67	40	141	10.20	9.45	8.25	10.35	3.67	4	190

Specimens are numbered from the butt end.

Initial solution: temperature 20°C, pH 2.30

Final solution: " 18°C, pH 2.45

Table 6. Specimen and treatment data on redwood trees felled in August, 1974.
Steam temperature 120°C. Time to reach full steam pressure $1\frac{1}{2}$ h.

Impregnation	Tree-specimen No	Sapwood moisture in % after peeling	Sapwood moisture in % before impregnation	Bulk density oven-dry, g/cm³	Mean diameter, mm	Max sapwood depth mm	Calculated corr steaming time, h	Steaming charge	Vacuum after steaming	Specimen weight, kg before steaming	Specimen weight, kg after steaming	Specimen weight, kg after conditioning	Specimen weight, kg after impregnation
OPM 4 hours	I-1	96	62	0.56	185	80	6.3	1	-	17.2	16.1	14.5	18.6
	I-4		68		163	60	4.7	2	+	12.4	11.1	10.4	13.5
	II-3	100	68	0.58	145	60	4.0	3	-	10.1	9.6	8.7	10.5
	II-6		65		136	50	3.5	4	+	8.5	7.8	7.0	9.3
	III-2		58		141	53	4.0	3	-	9.8	8.8	8.1	10.1
	III-5	105	69	0.60	135	50	3.8	4	+	8.3	7.9	7.0	8.8
Bethell 2 hours' pressure	I-3	106	54	0.55	168	60	4.8	2	-	12.7	11.9	10.2	14.7
	I-6		70		158	55	4.4	3	+	11.9	10.6	9.9	13.7
	II-2		59		152	63	4.5	3	-	11.0	9.8	9.1	12.6
	II-5	106	64	0.55	138	55	3.6	4	+	8.8	8.3	7.3	10.3
	III-1	95	58	0.61	155	70	4.8	2	-	12.2	11.5	10.1	13.6
	III-4		61		135	50	3.8	4	+	8.6	7.7	7.1	9.8
Bethell 1 hour's pressure	I-2		61		174	62	5.2	2	-	13.7	13.2	11.4	16.1
	I-5	113	77	0.55	160	57	4.4	3	+	12.1	11.6	10.4	14.2
	II-1	95	69	0.58	155	78	4.8	2	-	12.4	11.8	10.0	14.2
	II-4		61		141	55	3.7	4	+	9.2	8.2	7.6	10.9
	III-3	100	63	0.58	137	50	3.6	4	-	9.1	8.7	7.7	10.4
	III-6		65		125	48	3.2	4	+	8.8	7.2	6.5	9.2

Charge	steaming time
1	6.3 h
2	5.0 h
3	4.3 h
4	3.6 h

	Conc Boliden K33	pH	Temperature °C
Initial	2.30 %	2.45	21
Final	2.30 %	2.55	19

Table 7. Analysis of sapwood in specimens with Bethell treatment and 2 hours' pressure. Redwood felled in August, 1974. Results are given in percent.

Tree-specimen No	Vacuum after steaming	Outer third			Middle third			Inner third		
		Cu	Cr	As	Cu	Cr	As	Cu	Cr	As
I-3	-	0.32	0.35	0.49	0.15	0.16	0.27	0.08	0.10	0.21
I-6	+	0.32	0.35	0.52	0.13	0.14	0.25	0.04	0.06	0.13
II-2	-	0.27	0.30	0.44	0.12	0.13	0.23	0.05	0.07	0.13
II-5	+	0.32	0.44	0.48	0.17	0.18	0.32	0.06	0.08	0.16
III-3	-	0.23	0.36	0.37	0.10	0.11	0.19	0.07	0.08	0.14
III-4	+	0.31	0.34	0.49	0.16	0.18	0.32	0.01	0.03	0.07

Table 8. Specimen and treatment data on redwood trees felled in January 1975.
Steam temperature 120°C. Temperature at sapwood-heartwood interface 105°C.
Time to reach full steam pressure 1½ h.

Tree and Specimen No	Impregnation			Conditioning days	Sapwood moisture ratio %		Buld density g/cm^3 Oven-dry weight	Mean diameter mm	Max sapwood depth mm	Steaming time h	1 h vacuum after steaming	Specimen weight kg			
	OPM	Bethell	Schedule h		After peeling	Before impregnation						Before steaming	After steaming	Before impregnation	After impregnation
I-4	x		16	-	126	126	0.48	145	50	3.61				9.60	10.70
II-8	x		16	-	111	111	0.51	120	43	2.61				7.25	8.05
III-4	x		16	-	104	104	0.52	145	45	3.61				11.20	12.25
I-8	x		22	-	124	124	0.49	120	50	2.61				7.05	8.00
II-2	x		22	-	113	113	0.50	150	50	3.61				10.65	11.85
III-6	x		22	-	126	126	0.51	145	45	3.61				9.60	11.10
I-2	x		6	3	108	72	0.48	155	55	3.61		11.10	10.45	9.15	13.45
II-6	x		6	3	111	70	0.51	130	50	3.11		8.65	8.20	6.95	9.70
III-1	x		6	3	96	72	0.51	155	50	4.06		13.35	12.96	11.55	15.00
I-5	x		4	3	131	95	0.48	135	50	3.11		9.10	8.65	7.65	10.05
II-9	x		4	3	129	77	0.51	115	43	2.61		7.45	7.25	5.75	7.55
III-3	x		4	3	104	73	0.52	150	45	3.61		11.85	11.20	10.15	13.10
I-3		x	2	3	126	81	0.48	150	50	3.61	x	10.20	8.95	8.15	11.90
II-7		x	2	3	111	67	0.51	125	45	3.11	x	7.25	6.40	5.70	8.40
III-2		x	2	3	100	65	0.52	150	52	3.61	x	12.80	11.45	10.60	14.90
I-6		x	2	3	124	88	0.48	130	50	3.06		8.40	8.00	7.05	9.85
II-1		x	2	3	109	83	0.50	170	52	4.11		14.65	14.30	12.85	16.20
III-5		x	2	3	112	79	0.51	145	45	3.37		10.70	10.05	9.05	12.40
I-7		x	2	10	124	57	0.48	130	50	3.06	x	7.80	6.85	5.45	9.35
II-3		x	2	10	113	62	0.50	145	52	3.37	x	9.70	8.55	7.40	11.00
III-7		x	2	10	126	68	0.51	140	45	3.06	x	9.80	8.70	7.30	11.20
I-9		x	2	10	132	87	0.50	110	50	2.37		7.45	7.25	6.00	8.85
II-4		x	2	10	114	65	0.51	135	50	3.06		8.00	7.65	6.15	9.35
III-8		x	2	10	130	79	0.51	135	43	3.06		9.20	8.75	7.15	10.50
I-10		x	2	17	132	53	0.50	110	50	2.37		6.60	6.25	4.35	7.60
II-10		x	2	17	130	54	0.51	115	43	2.37		6.40	6.15	4.10	7.45
III-10		x	2	17	140	59	0.52	130	43	3.06		8.60	8.15	5.70	10.00

2.8 % Boliden K33. Initial and final solution temperature 13°C

" " " pH 2.55

Table 9. Preservative distribution in natural rounds of redwood felled in January 1975.
Steamed and conditioned before 2 hours Bethell treatment.
Content of elements is given in percent.

Vacuum after steaming	Conditioning days	Tree No	Part of sapwood								
			outer third			middle third			inner third		
			Cu	Cr	As	Cu	Cr	As	Cu	Cr	As
1 h	10	1	0.46	0.49	0.69	0.28	0.26	0.51	0.19	0.20	0.39
		2	0.36	0.39	0.58	0.26	0.26	0.45	0.12	0.13	0.22
		3	0.41	0.44	0.66	0.23	0.22	0.42	0.07	0.07	0.12
none	17	1	0.45	0.48	0.69	0.29	0.27	0.53	0.11	0.12	0.25
		2	0.48	0.50	0.74	0.34	0.32	0.65	0.13	0.16	0.30
		3	0.48	0.52	0.74	0.37	0.35	0.61	0.20	0.19	0.38

Table 10. Bethell impregnation of green redwood boards with 3.10 % Boliden K33. Felled and sawn early in September 1974. Grown at Suntetorp near Skövde.

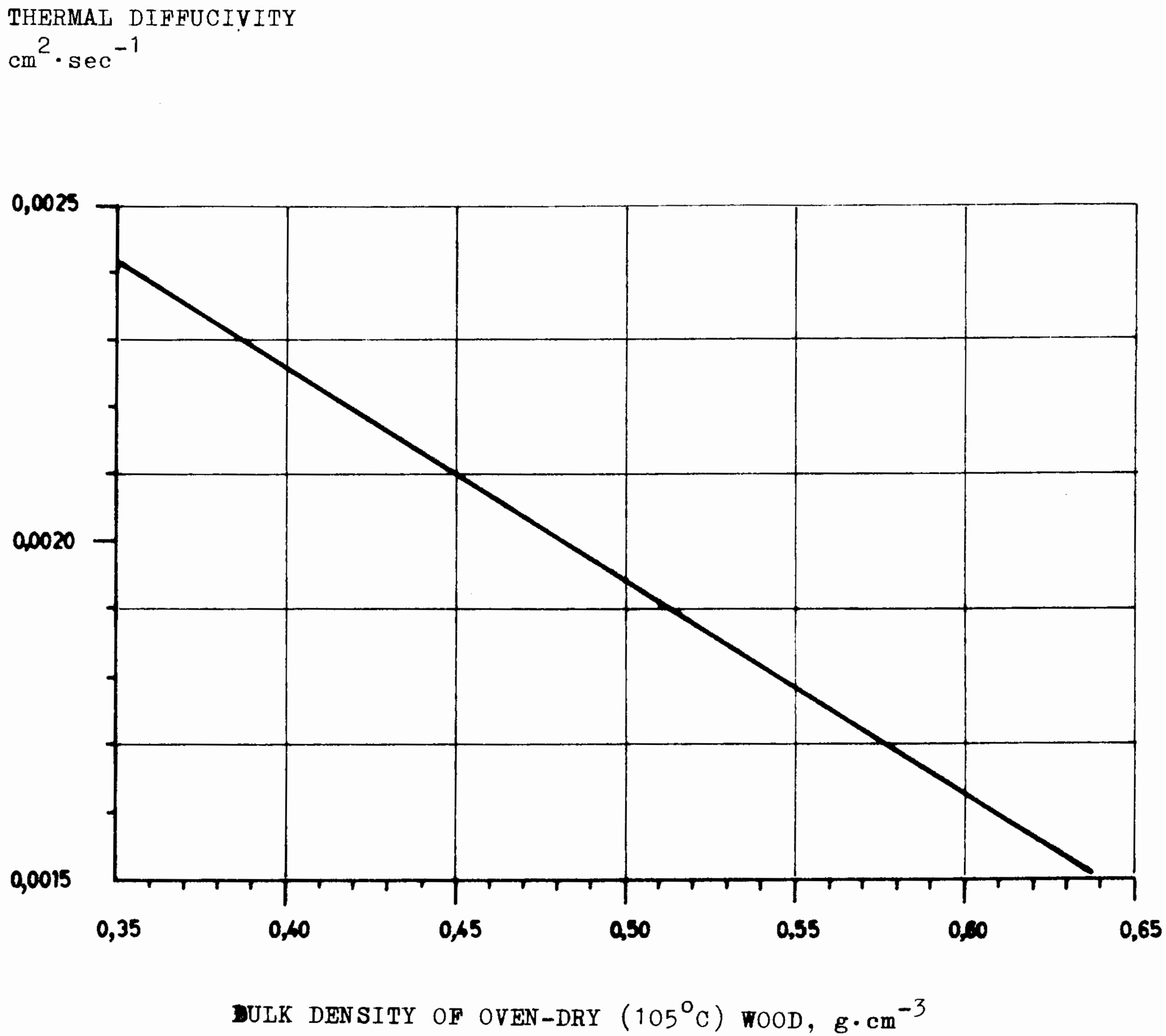
Tree Board	Drying time before steaming days	Moisture ratio, %				Retention in % on oven dry weight	
		Initial	After drying	After steaming	After condi- tioning	Of solu- tion	Of salt
I-1	0	134	-	118	87	60	1.86
2	0	120	-	111	91	65	2.02
3	0	90	-	81	66	60	1.86
4	0	76	-	71	56	51	1.58
5	0	89	-	77	60	62	1.92
6	0	127	-	115	93	64	1.98
I-1	7	130	99	96	60	86	2.66
2	7	110	85	82	66	75	2.32
3	7	81	64	63	52	62	1.92
4	7	70	57	55	45	54	1.69
5	7	100	49	52	40	98	3.04
6	7	135	82	82	59	106	3.28
I-1	14	126	76	68	35	124	3.85
2	14	99	54	57	44	95	2.94
3	14	71	38	42	32	71	2.20
4	14	67	46	44	32	56	1.74
5	14	110	68	62	42	65	2.01
6	14	143	100	86	63	106	3.28
II-1	0	142	-	114	71	84	2.60
2	0	127	-	108	81	74	2.30
3	0	63	-	58	45	57	1.77
4	0	62	-	60	44	60	1.86
5	0	114	-	102	90	89	2.76
6	0	138	-	120	81	92	2.85
II-1	7	137	95	90	49	83	2.56
2	7	120	104	95	75	79	2.45
3	7	63	44	44	31	66	2.04
4	7	62	48	48	35	62	1.92
5	7	115	86	84	67	94	2.92
6	7	140	107	102	76	97	3.61
II-1	14	132	81	73	39	117	3.63
2	14	111	65	67	52	97	3.00
3	14	60	31	32	24	74	2.29
4	14	62	34	37	28	74	2.29
5	14	115	58	58	44	109	3.40
6	14	141	71	66	51	130	4.03

APPENDIX FORTRAN PROGRAMME FOR CALCULATION OF HEAT PENETRATION AT STEAMING OF ROUNDS

Programmed by Hans Alsholm

```
      LIBRARY(SUBGROUPFSCE)
      LIBRARY(SUBGROUPSRF7)
      PROGRAM(PENE)
      OUTPUT 1=LPO
      INPUT 2=CRO
      END
      MASTER PENETR
      DIMENSION ROOT(8), TID(15,10)
      DATA ROOT/2.405,5.52,8.654,11.792,14.931,18.071,21.212,24.352/
      WRITE(1,890)
      READ(2,891)H,ITI
      WRITE(1,892)
      READ(2,893)I1,I2,I3
      WRITE(1,894)
      READ(2,893)I4,I5,I6
      WRITE(1,895)
      READ(2,893)I7,I8,I9
      K=0
      DO 200 ITS=I1,I2,I3
      DO 200 ITR=I4,I5,I6
      K=K+1
      DO 120 IA=I7,I8,I9
      ITID=0
      DO 120 IP=1,10
      IR=IA-IP
      IF (IR-1) 70,80,80
   70 IR=1
   80 ITID=ITID+180
      SUM=0
      DO 100 N=1,8
      X=ROOT(N)
      Z=X*IR/IA
      CALL F4J0(Z,Y0)
      CALL F4J1(X,Y1)
  100 SUM=SUM+Y0/Y1/X*EXP(-H*(X/IA)**2*ITID)
      TR=ITS+2*(ITI-ITS)*SUM
      IF (TR-ITR) 80,120,120
  120 TID(IA,IP)=(ITID-180)/3600.
      WRITE(1,898)
      DO 125 J=1,5
  125 WRITE(1,899)
      WRITE(1,900)K,ITR
      WRITE(1,901)ITS
      WRITE(1,902)ITI
      WRITE(1,903)H
      WRITE(1,899)
      WRITE(1,904)ITR
      WRITE(1,905)(I,I=1,10)
      DO 150 IA=I7,I8,I9
      ID=2*IA
      IF (IA-11) 135,135,130
```

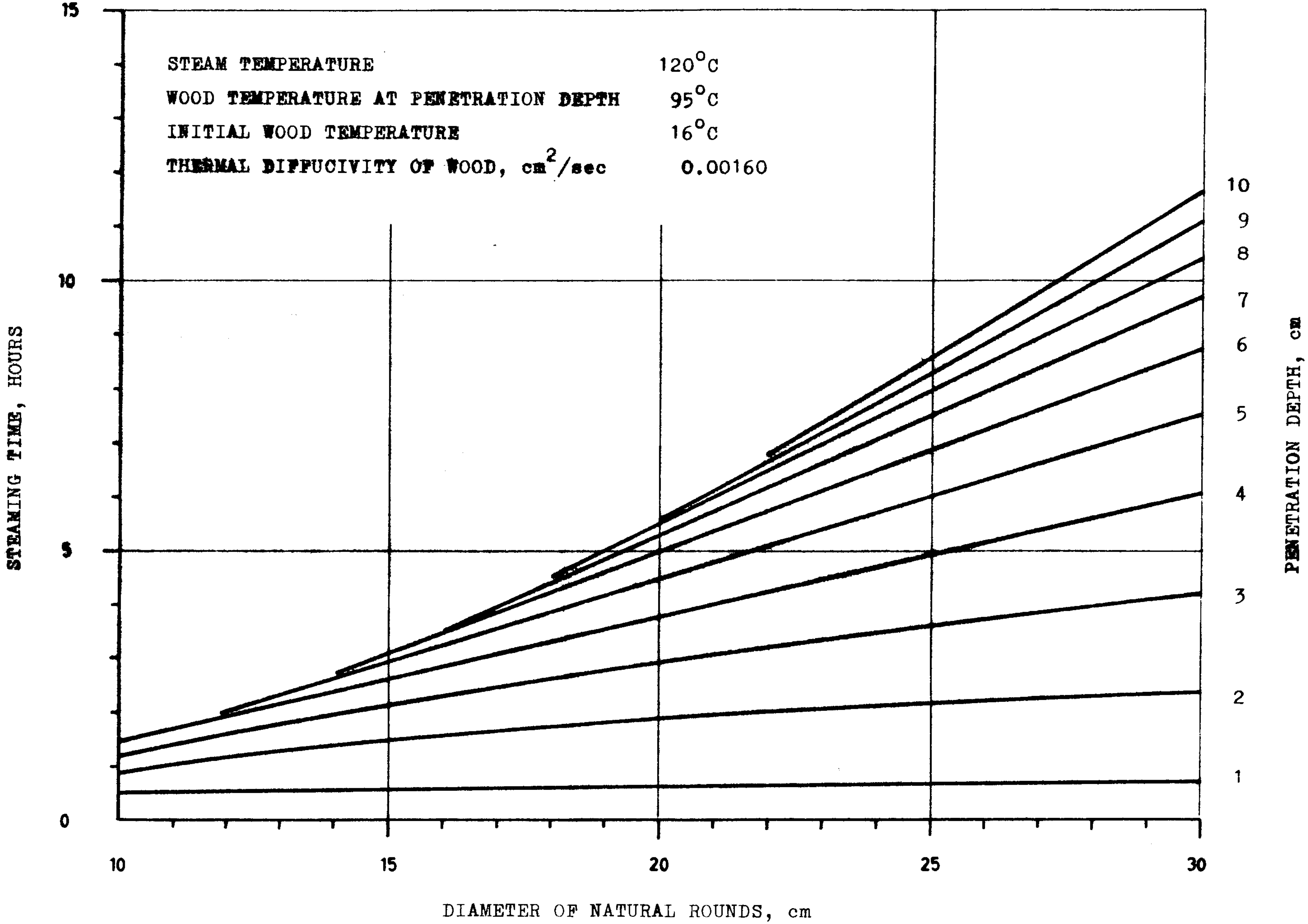
```
 130 IB=10
     GO TO 140
 135 IB=IA-1
 140 WRITE(1,906)ID,(TID(IA,IP),IP=1,IB)
 150 CONTINUE
 200 CONTINUE
     STOP
 890 FORMAT(1X,52HGIVE THERMAL DIFFUSIVITY AND INITIAL TEMP. OF TIMBER)
 891 FORMAT(F0.0,I0)
 892 FORMAT(1X,44HGIVE START AND END VALUES AND STEPLENGTH FOR/
     *1X,14HA. STEAM TEMP.)
 893 FORMAT(3I0)
 894 FORMAT(1X,32HB. TEMP. AT DISTANCE R AT TIME T)
 895 FORMAT(1X,19HC. RADIUS OF TIMBER)
 898 FORMAT(1H1)
 899 FORMAT(1X)
 900 FORMAT(1X,5HTABLE,I3,15H. TIME TO REACH,I4,38H DEG.C AT DIFFERENT
     *PENETRATION DEPTHS)
 901 FORMAT(11X,17HSTEAM TEMPERATURE,I4,6H DEG.C)
 902 FORMAT(11X,29HINITIAL TEMPERATURE OF TIMBER,I3,6H DEG.C)
 903 FORMAT(11X,19HTHERMAL DIFFUSIVITY,F8.5,10H SQ.CM/SEC)
 904 FORMAT(1X,38HTIMBER DIAM.  TIME IN HOURS TO REACH,I4,
     *30H DEG.C AT PENETR. DEPTHS IN CM)
 905 FORMAT(6X,2HCM,4X,10I6)
 906 FORMAT(5X,I3,5X,10F6.1)
     END
     FINISH
****
```



THERMAL DIFFUCIVITY OF GREEN WOOD HEATED IN STEAM

PREPARED FROM DATA BY J D MacLean

FIGURE 1



STEAMING GRAPH

FIGURE 2

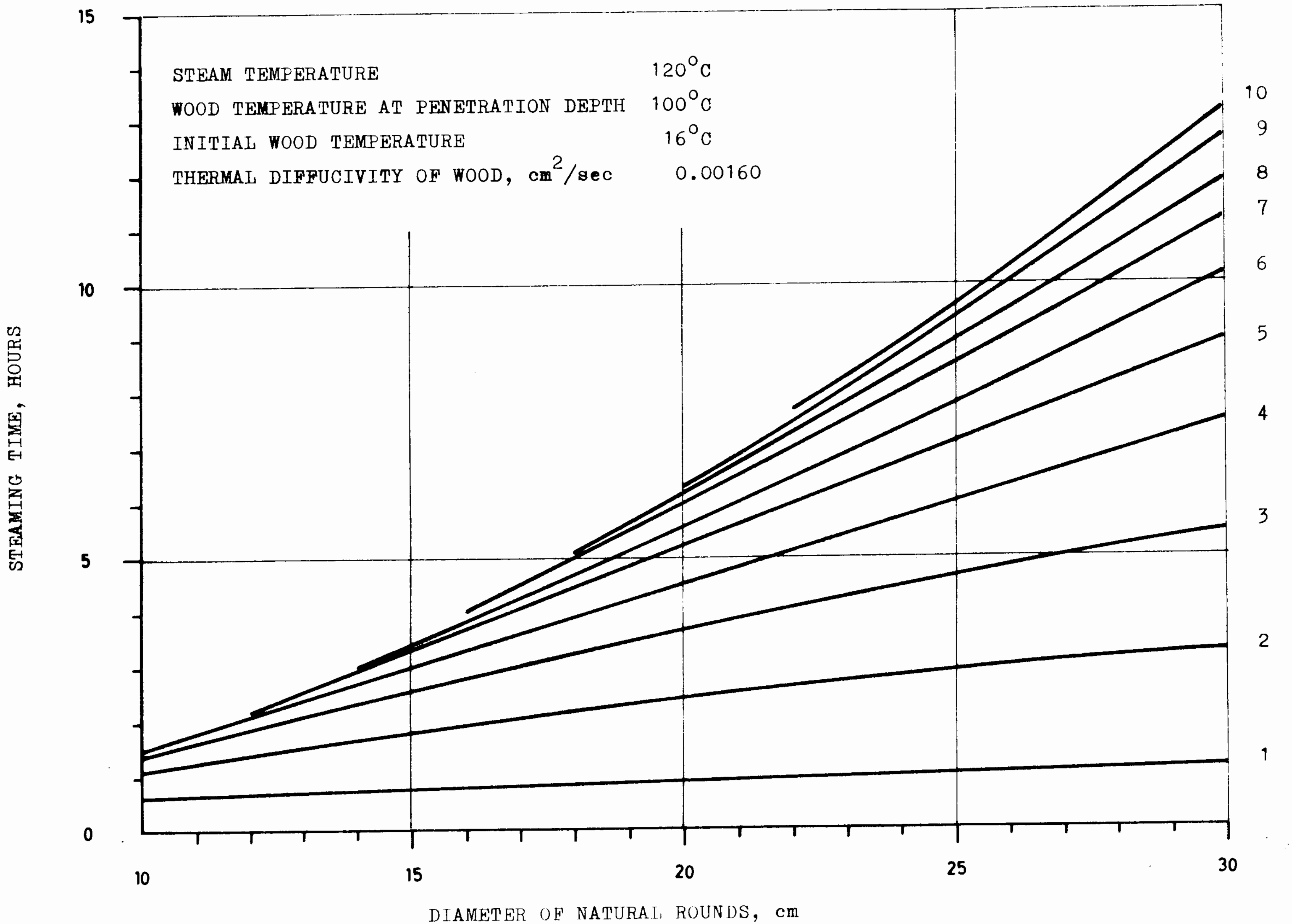
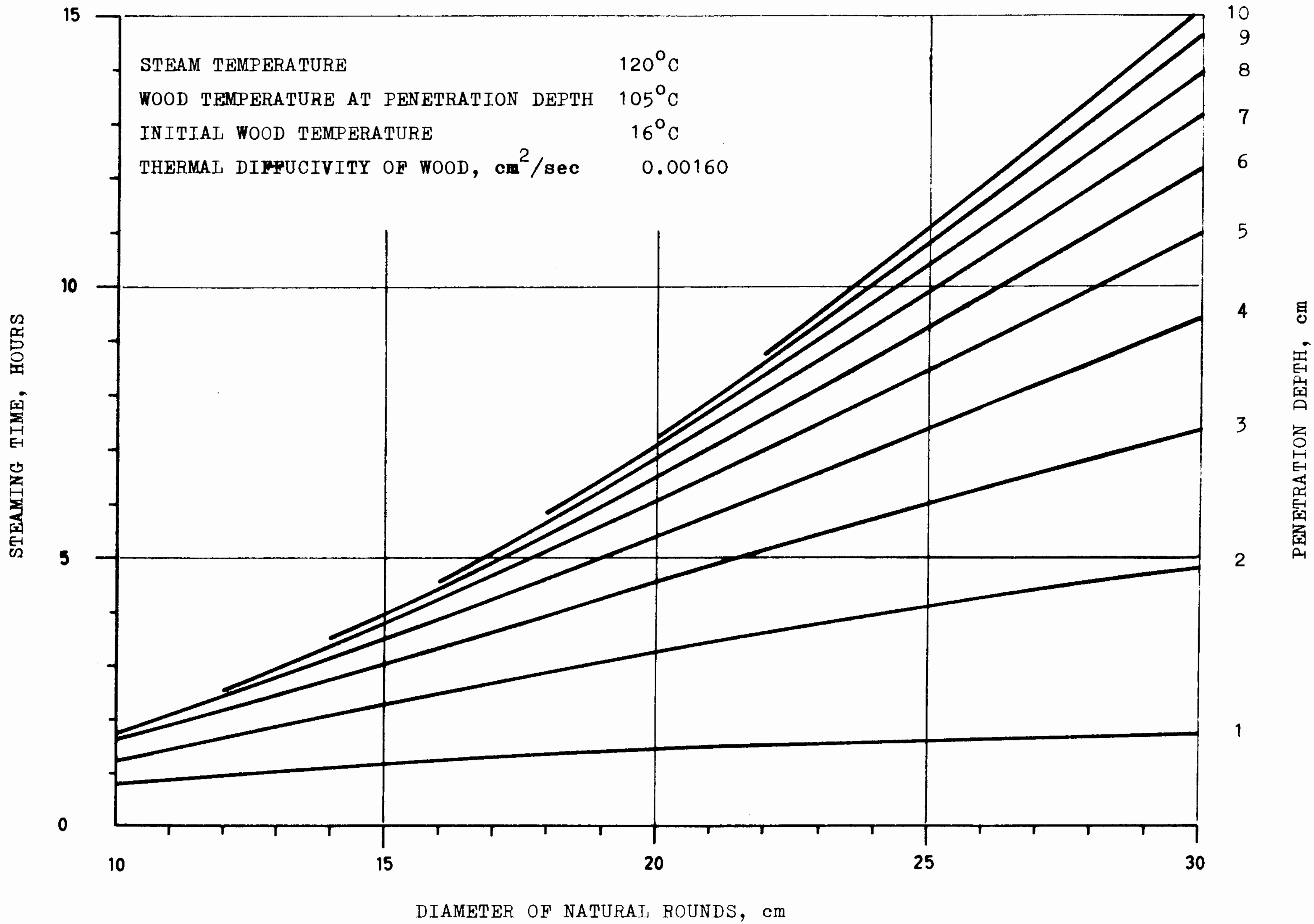


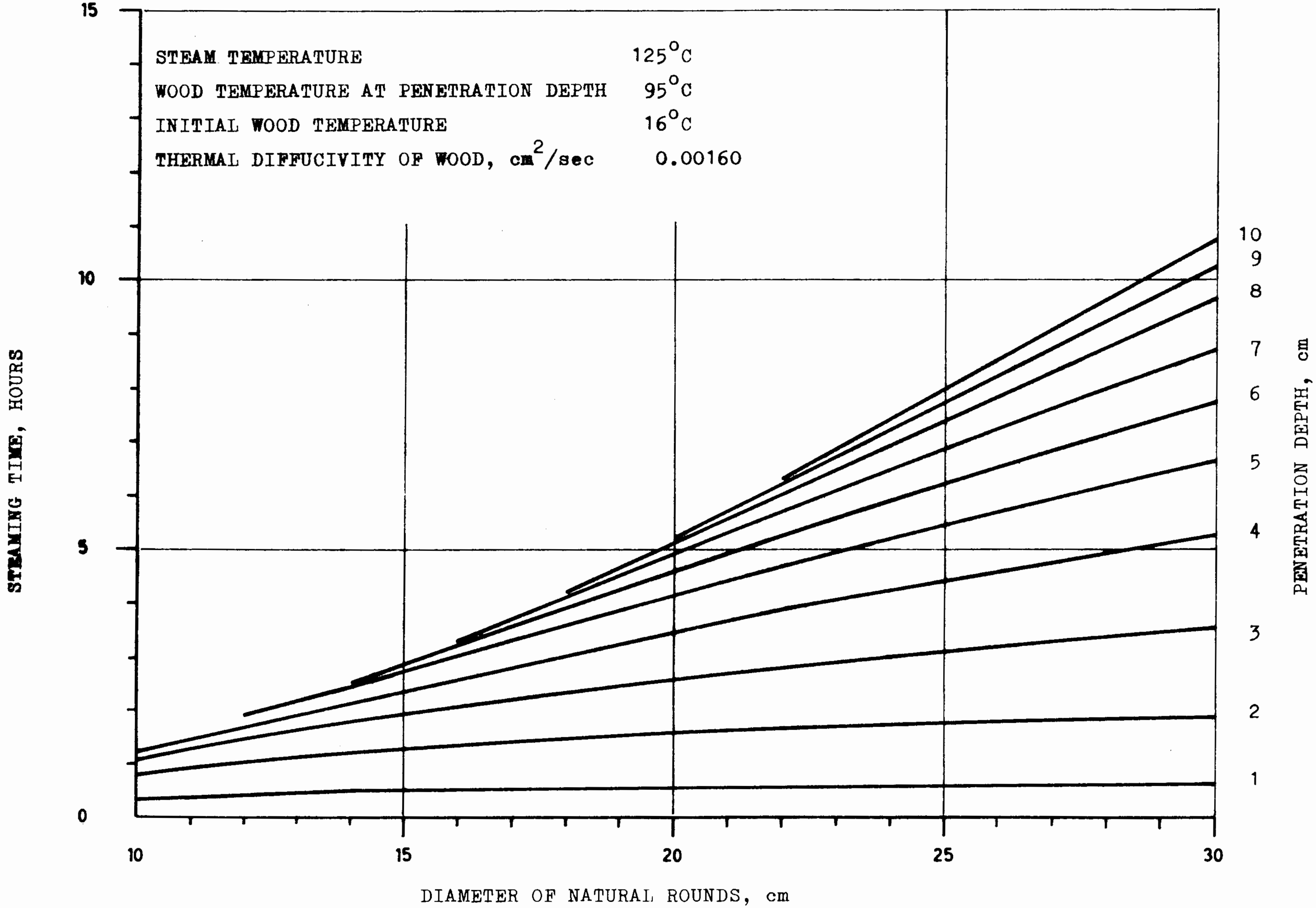
FIGURE 3

STEAMING GRAPH



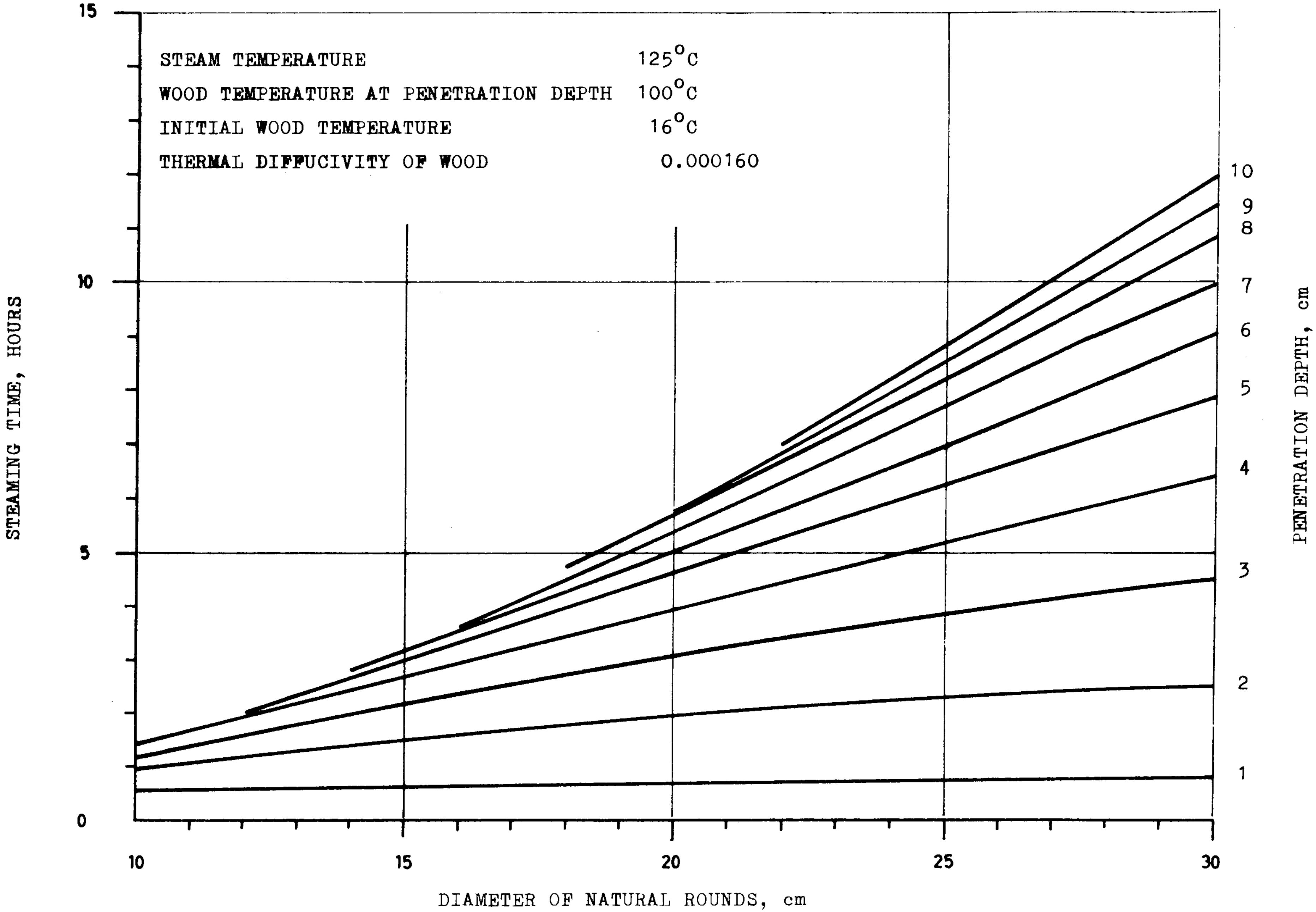
STEAMING GRAPH

FIGURE 4



STEAMING GRAPH

FIGURE 5



STEAMING GRAPH

FIGURE 6

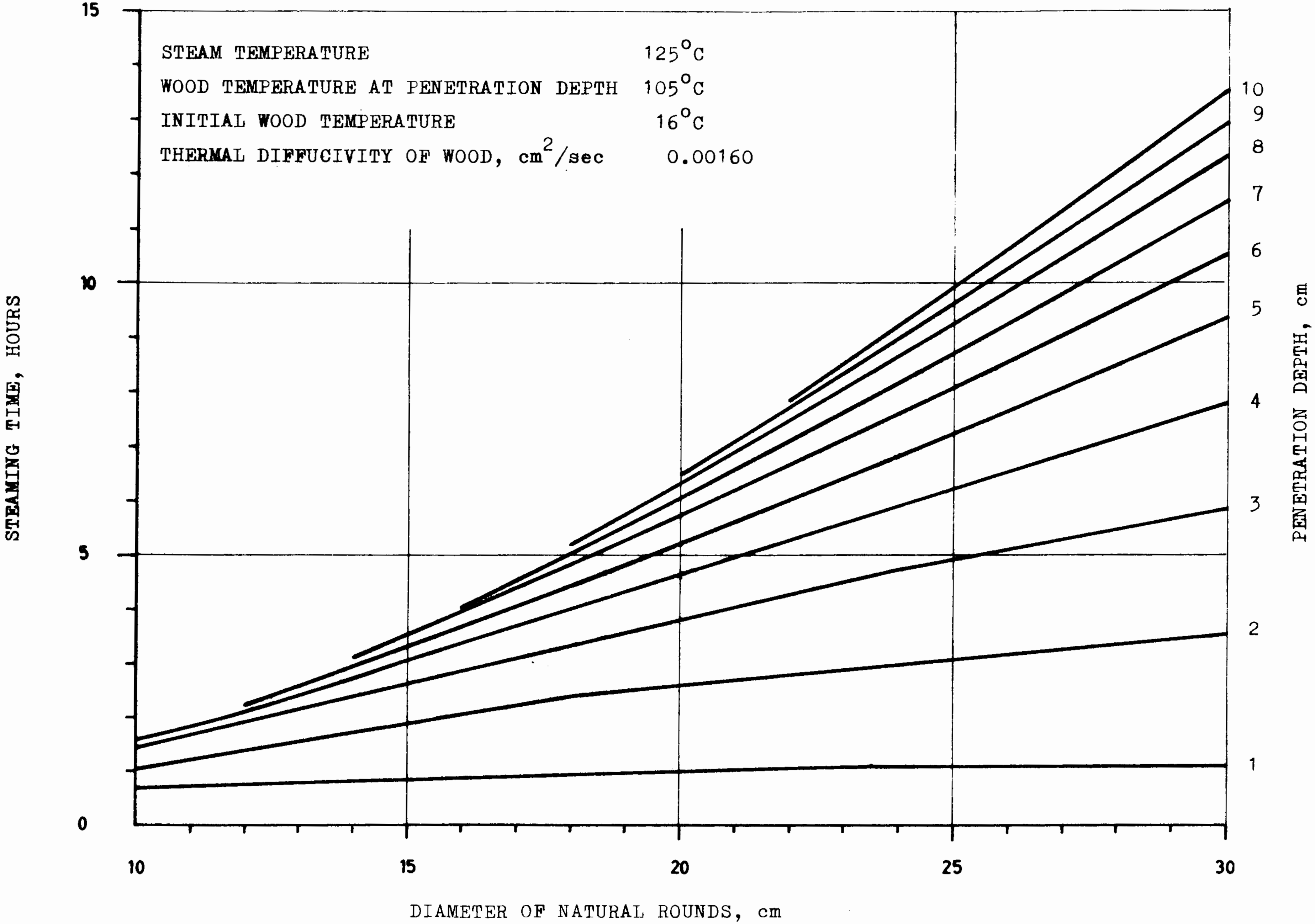


FIGURE 7

STEAMING GRAPH