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Title: The Economic Feasibility of Preheating Douglas-fir Blocks Prior to Peeling

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Past research and industrial sources have implied that preheating Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] prior to peeling veneer was economically feasible.

To test this, the effect of treatment temperature on veneer yield and thickness variation for three diameter classes of low grade Douglas-fir logs was studied and related to the cost of preheating.

Test results showed that pre-heating No. 3 Douglas-fir Sawmill logs to a peel temperature range of 50°F to 120°F had no statistical effect on veneer value, total yield, grade yield, or veneer sheet width yield of 12, 18, and 24 inch diameter blocks. Block diameter, however was found to have a highly significant effect on veneer value expressed as the value of the percentage of the block volume recovered as marketable green veneer. Eighteen inch diameter blocks had the greatest total, grade, and full sheet recovery per unit volume of initial block diameter. Twenty-four inch diameter blocks had the least recovery and value while the 12 inch blocks were intermediate. Veneer thickness variation was found to be independent of peel temperature but significantly influenced by block diameter.

The reason for the block diameter-veneer yield and thickness variation interaction was not investigated but was probably due to a

complex interaction of wood properties at various diameters and the changing in the lathe setting angles due to the differences between diameters.

A microprocessor based data acquisition system was built to record the output of a non-contact infrared temperature sensing instrument that measured the block temperture profile during peeling. The variability of temperature found within the blocks suggest the effects of heating would vary greatly for any one block. The microprocessor proved to be a valuable research tool that has many research uses but more importantly, many industrial process control applications.

The equation describing unsteady state transfer for an infinitely long cylinder was solved via numerical analysis to theoretically estimate heating times for veneer blocks. The model may not be applicable to wood because the assumptions used to solve the problem, i.e. constant diffusivity and homogenity of the material, are violated when dealing with wood.

The Economic Feasibility of Preheating Douglas-fir Blocks Prior to Peeling

by

Richard Baskin

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I. INTRODUCTION

Past research and many industrial sources have indicated that preheating Douglas-fir [Pseudotsuga menziesii (Mirb.) Fanco] prior to peeling for veneer is economically viable. The strength and elastic properties of wood vary inversely with temperature at a given moisture content (Pashwin and de Zeeuw, 1970), and it is thought that preheating exploits these properties of wood. It is reasoned that since less force is necessary to machine the wood surface, a more desirable veneer for the final end product, plywood, is obtained.

The advantages of preheating Douglas-fir are thought to be numerous. Grantham and Atherton (1959) and Lutz (1960, 1974) cite some of the more commonly claimed benefits. The potential advantages of preheating Douglas-fir peeler blocks are:

1. Preheated blocks give a smoother uniform peel of tighter veneer.

2. Preheating softens knots which permits peeling with a sharper knife, reduces the frequency of knife sharpening, and lengthens knife life.

3. Preheating results in improved yield recovery into volume and grade. Also, by reducing splits, more four foot and two foot wide veneer is produced.

4. Preheating gives a higher percentage of higher quality veneer of more uniform thickness, shallower lathe checks, and decreased surface roughness.

5. Preheating produces veneer that lies flat for improved scanner performance on automatic veneer clippers. Also, the veneer handles easier, resulting in fewer broken sheets for increased wide sheet yield.

6. Preheating softens the wood reducing the torque required for peeling. Fewer spin-outs and reduced power consumption result.

7. Preheating elevates the temperature of the veneer produced and sufficient amounts of heat remain to evaporate moisture from the veneer, allowing shorter drying times. The residual heat also reduces the amount of energy necessary to heat the veneer to temperatures that drive off the remaining moisture.

8. Preheating is absolutely necessary to peel frozen Douglas-fir blocks if satisfactory veneer is to be produced.

A survey of American Plywood Association (APA) member mills conducted for this study reported substantial yield gains for heated versus unheated Douglas-fir blocks of anywhere from five to 30 percent. Survey results also revealed a wide range of opinion as to the benefits of preheating from immeasureable to $1.5 million annually. Most respondents could not identify by what dollar amount the benefits of preheating outweighed the costs, however.

Improved veneer quality is often claimed as a result of preheating. Veneer quality has been defined by Hailey and Hancock (1973) as "technical term used in describing or evaluating the effect of the peeling process on the physical properties, namely, thickness, roughness, and lathe-check depth, of green veneer sheets." Veneer quality, therefore, is different than veneer grade, the latter being an evaluation of veneer based on appearance and physical properties after machining is complete. Veneer in the same grade could exhibit different veneer quality.

An economic evaluation of the feasibility of preheating Douglas-fir veneer blocks must follow two principles of engineering economy. First, only differences among alternatives are relevant in their comparisons. Second, in comparing alternatives, it is desirable to make all comparisons commensurable with one another. Consequences (differences) should be expressed in numbers and the same units should apply to all the numbers. "In economic discussions, money units are the only units that meet the foregoing specifications." (Grant and Ireson, 1970). Except for veneer thickness variation, it is difficult to assign a monetary value to the differences in peel quality of green veneer. However, veneer grade differences are measured and assigned a monetary value in the market place. Yield gains in veneer grade, volume, and sheet width are claimed as a result of preheating. Since these yield differences can be assigned money units, it was decided that yield differences between heated and unheated Douglas-fir blocks could be quantified.

Objectives

The study was developed to determine the economic feasibility of preheating Douglas-fir veneer blocks prior to peeling based on the value added to the veneer versus the capital investments and operating cost of the required equipment.

Belief that preheating was economically feasible led to incorporating two levels of heating in an attempt to find a more optimal peel temperature. In addition, recognizing that the Douglas-fir peelers currently available are of a low grade and small diameter, the study was designed to test for differences in heating benefits between 12, 18, and 24 inch diameter Douglas-fir blocks of a low log grade.

Since differences in peel temperature were to be quantified, a continuous monitoring system was developed to measure block temperatures at the lathe. Furthermore, in an attempt to develop better estimates of block heating times, a numerical analysis of block heating was conducted.

II. REVIEW OF THE LITERATURE

Veneer peeling research has been conducted by numerous researchers. Lutz (1974) and Palka (1974) have made concise, systematic reviews of information accumulated in the area of veneer peeling. Preheating (preconditioning) of veneer blocks of many species, including Douglas-fir, is discussed as it influences peel quality and veneer yield. Unfortunately, little research has emphasized economic considerations of preheating Douglas-fir peeler blocks.

Yield Gains as a Result of Preheating

Grantham and Atherton (1959) conducted an extensive study to quantify the preheating of Douglas-fir peeler blocks and its effects on mill profitability. Thirty-five Douglas-fir No. 2 Peeler logs and 39 Douglas-fir Special Mill logs were sawn into matched blocks, one of which was peeled at 140^{o}F and the other was peeled cold. They report that the major advantage of heating Douglas-fir blocks was an increased recovery of A-grade veneer. The increased recovery of A-grade veneer provided the economic justification for preheating high grade Douglas-fir logs.

Grade recovery data for No. 2 Peelers showed a yield of 60 percent A-grade veneer heated versus 48 percent for the unheated blocks. Recovery of A-grade veneer was 17 percent and 11 percent from heated and unheated blocks of Special Mill logs, respectively. Overall, the matched blocks from No. 2 Peelers, heated and unheated, produced almost identical yields of 10,020 thousand square feet, net log scale (MNLS) heated versus 9,960 MNLS unheated. A four percent yield increase was realized for Special Mill logs when preheated.

Sheet width is important to mill profits as full sheets (4 feet by 8 feet) have a higher value than half sheets (2 feet by 8 feet), random widths (less than 2 feet by 8 feet nominal) and fishtails (less than 8 feet long). The No. 2 Peelers yielded 25 percent more full sheets of A-grade when heated. Heated Special Mill log blocks yielded 51 percent more full sheets of A-grade veneer than unheated blocks. Considering all grades, No. 2 Peelers yielded 65 percent full sheets heated and 64 percent unheated. Special Mill log blocks yielded 61 percent full sheets and 53 percent full sheets for heated and unheated blocks, respectively. The increased gain with respect to production of full width sheets is in the A-grade veneer for both log grades.

Value added to the veneer as a result of preheating was $5.17 MNLS for No. 2 Peelers and $13.65 for Special Mill logs (Table 1). For No. 2 Peelers, increased A-grade yield accounted for almost all of veneer value difference. In fact, the value of veneer in grades B, C, and D produced by the unheated blocks exceeded that of the heated blocks. For Special Mill logs, A-grade veneer accounted for most of the value added to the veneer as a result of preheating. A figure of $0.82 MNLS was assigned as the cost of preheating, resulting in a net gain of $4.35 and $12.83 MNLS for preheating No. 2 Peelers and Special logs, respectively (Molinos (1974) estimated production costs of $1.19 per 1000 square feet, 3/8-inch basis for preheating softwood veneer blocks in California).

Corder and Atherton (1963) report the results of an unpublished

Table 1. Value of Veneer Recovered from No. 2 Peelers and Special Mill Logs (Grantham and Atherton, 1959).

	No. 2 Peelers		Special Mill Logs	
Grade	Unheated	Heated	Unheated	Heated
A	$116.52	$143.51	$ 23.19	$ 39.15
B	31.33	17.73	13.05	16.18
C	28.58	26.29	23.45	20.04
D	17.16	13.20	68.28	66.86
Other	11.16	9.19	12.10	9.49
Total	$204.75	$209.92	$138.07	$151.72

study gave similar increases of A-grade veneer. An increased value of $6.00 per thousand board feet, net log scale, was found for Douglas-fir blocks peeled at about 140°F compared to matched blocks peeled at 40°F. Lutz (1960, 1974), Palka (1974) and Baldwin (1975) cite Grantham and Atherton when reporting that heating does pay for Douglas-fir, failing to note that the cost advantage of preheating was justified by the increased recovery of full sheets of A-grade veneer.

Preheating Effects on Peel Quality

Peel quality involves primarily three physical properties of veneer, viz., thickness, roughness and lathe-check depth (Hailey and Hancock, 1973). Suitable definitions, standards, and measurement techniques for peel quality have been researched. Myrnuk (1972) pointed out the existing measurement methods are inadequate as the volume of veneer to be measured increases.

Veneer Thickness

Veneer thickness has been defined as the depth of wood layer removed during one revolution of the block being peeled. A tolerance limit for thickness has been suggested as the average veneer thickness peeled within a given block section plus or minus 0.008 inch. This standard was found to be obtainable in mill situations (Hailey and Hancock, 1973; Hancock, 1977).

Block temperature at the time of peeling has been found to have little effect on veneer thickness variation when peeling Douglas-fir veneer. Grantham and Atherton (1959) found no difference in thickness variation as as result of peeling heated blocks. This conclusion was supported by Corder and Atherton (1963). They reported greatest thickness variation at 200°F and least at 120°F. Although the thickness standard and tolerance limit had not been developed, their measurements conformed to the definition. Lutz (1967) found no heating effect on veneer thickness in southern pine.

While peel temperature has been found to have no effect on veneer thickness variation, lathe settings have been found to have significant impact on veneer thickness variation. Palka (1974) and Lutz (1974) should be referenced for detailed discussions of lathe variables important to control green veneer thickness.

Veneer Roughness

Veneer roughness is the depth of which wood is removed during the peeling process below the theoretical plane surface of the veneer. Experience showed that a veneer with a depth of roughness greater than 0.020 inch was substandard (Hailey and Hancock, 1973). The measurement methods for veneer roughness, however, have not been successful at mill production speeds and conditions. Peters and Mergen (1971) reviewed various roughness measurement systems and concluded a direct displacement transducer offers the most promise. A distinct disadvantage of this approach is that contact with the wood is necessary. George and Miller (1970) have developed a roughness detector for moving veneer consisting of light source, a baffle riding close to the veneer surface, and a light sensor. Experiments showed that the equipment worked well, i.e. sensed differences in veneer roughness. Recent advances in computer capabilities for declining prices suggests this sensor could function at mill production levels and speed.

Corder and Atherton (1963) found temperature only had a slight effect on roughness of veneer peeled from Douglas-fir heartwood. Sapwood veneer gave higher roughness at high temperatures. They concluded that veneer roughness was not improved by heating the blocks before peeling. Grantham and Atherton (1959) report the degrade for roughness was only in the A-grade veneer of No. 2 Peelers. Practically no degrade for roughness was observed for either hot or cold blocks for Special Mill logs. Palka (1974) also states that veneer roughness seems hardly affected by heat treatment.

Gluing difficulties are said to occur due to rough veneer (Lutz, 1974). Tests at the Forest Products Laboratory (Lutz, 1960) have shown that loose, 3/16 inch Douglas-fir veneer cut from bolts at room temperature and with poor lathe settings is difficult to glue with cold setting adhesives. Veneer from heated bolts did not experience this problem. No analysis was offered in the report as to whether it was more economically sound to adjust lathe settings or to heat the bolts to achieve reduction of the observed gluing difficulties. In a sample of veneers peeled under mill conditions, Bryant and Hoerber (1967) report that veneer roughness of a magnitude produced in an actual mill did not influence glue spreads or glue spread variation.

Southern pine peeling experiments (Lutz, 1967) showed that veneer roughness was not significantly affected when cutting clear wood at various temperatures.

Lathe Check Depth

Lathe-check depth is the average depth of penetration of the fractures on the loose side of a veneer sheet, which result from the bending action of the veneer sheet, expressed as a percentage of veneer thickness (Hailey and Hancock, 1973). The tolerance limit for lathe-check depth is set as a percentage of the average veneer thickness minus a sanding allowance of 0.030 inch. Symbolically,

$$LCD\ (\%) = \frac{Th - 0.030\ inch}{Th} \times 100$$

where

LCD (%) = lathe-check depth tolerance limit expressed as a percentage of average veneer thickness

Th = average veneer thickness

The tolerance limits for roughness and lathe-check depth were set by the Western Forest Products Laboratory of Vancouver, British Columbia and were reported by Hailey and Hancock (1973). It should be noted that the tolerance limit is not associated with degree of flexibility for optimal handling properties, but rather the limit is applied to sanded-panel production.

A temperature effect on lathe-check depth was found by Lutz (1960) and Corder and Atherton (1963). Lutz found that checks extended through 80 percent of the thickness of 1/10 inch veneer cut from unheated Douglas-fir blocks. Only 40 percent of veneer thickness was penetrated by lathe-checks from blocks cut to 160°F. Corder and Atherton (1963) found in general that depth of lathe-checks in veneer decreased as peeling temperatures increased. Also noted was that heartwood veneer from fine grained logs was decidedly tighter when peeled with increased nosebar pressure was necessary to produce tight veneer from cold peeled blocks.

Other Considerations

Tensile strength across the grain is related inversely to depth of lathe checks. Checks reduce the area of unfailed wood in sections parallel to the grain (Corder and Atherton, 1963). Tensile strength perpendicular to the grain was found to be higher for veneer peeled at 140°F and light nosebar pressure than for veneer peeled at room temperature with heavy pressure on the nosebar, although the lathe-check depth was greater with light pressure.

Bending strength parallel to the grain was found not to be affected by depth of lathe-check (Corder and Atherton, 1963). They found that an increase in strength may result in veneer peeled from heated blocks.

Spin outs were shown to generally decrease as temperature increased for basswood to be cut into 1/4-inch veneer (Lutz and Patzer, 1976). Faser (1975) reported a spin out decrease from seven to three percent by using longer heating times for blocks in a Swedish plywood plant. Lutz and Patzer (1976) further report that knife angle, pressure bar setting and cutting velocity effect torque (a torque greater than the block strength would cause a spin out) required to peel veneer. For example, the torque required to cut 1/4 inch basswood at room temperature could be varied by 2 to 1 depending on the knife and pressure bar setting. The reduction in torque when basswood was heated was of the same percentage (40 percent) as the decrease in torque the block could withstand due to increased temperature. No discussion as to the incremental cost ofchanging lathe settings versus cost of preheating was presented.

Grantham and Atherton (1959) also report that potential savings in drying time to lower moisture content of the sapwood (147 and 160 percent for heated and unheated blocks, respectively) may be offset by the higher moisture content (35 and 32 percent, heated and unheated, respectively) of the heartwood when it is considered that the volume of heartwood veneer dried on a fast schedule could be twice that volume dried on a slow schedule. They concluded that a conclusive statement relating block temperature at the time of peeling and drying times could not be made.

Peeling of Frozen Logs

Lutz (1974) states that it is impossible to cut veneer from frozen logs. Furthermore, he adds that the mill without heating facilties would be forced to shut down if the logs do freeze. He cites no studies when making these statements.

Heating of Blocks

If it is assumed that preheating of Douglas-fir blocks is justified, the equipment and procedures to heat blocks adequately to uniform temperatures must be specified. Various authors have examined the problem and some points of agreement and disagreement have been reached.

Theoretical Considerations

In the 1930s MacLean initiated research into the heat conduction of wood (1930, 1932). He approached the heating of logs theoretically to reduce the amount of testing necessary to estimate log heating parameters. The model MacLean analyzed is solved in this paper under the section "Block Heating Simulation." The discussion presented there addresses the effect of log diameter and final desired temperature on heating times and temperature variation along the log diameter.

Heating schedules for most commercial species, including Douglas-fir, have been determined (Fleisher, 1959; Feihl, 1972; Feihl and Godin, 1975; Lutz, 1978). Lutz (1974) gives examples of heating times as a function of block diameter.

Controversy exists as to the effect of heating medium (MacLean, 1952; Feihl, 1972; Briggs; 1975) on heating times. Lutz (1974) notes that block diameter, initial block temperature and temperature of the heating medium may affect heating times sufficiently to allow the controversial factors to be disregarded when making practical considerations.

Steinhagen (1977) reviewed the literature concerning the thermal conductive properties of wood, green or dry, from -40°C to +100°C in connection with a study on heat transfer in frozen logs. Arithmetic means for specific heat, thermal conductivity and thermal diffusivity from the various data sources were computed. No strong conclusion was reached and Steinhagen's final report is unpublished at this time although he has presented some new information on heating frozen hardwood logs (1977).

Feihl and Godin (1975) have reviewed heating of frozen and non-frozen lots for a number of commercial species. Their report presents a complete discussion of the practical aspects of block heating and should be referenced for more complete information.

Block Heating Systems

The two principle types of heating systems are vats and chests. There are three types of vats: water vats for submerged logs, covered vats for floating logs, and uncovered vats for floating logs. The three types of chests are steam chests where the steam is injected live into the chest, steam chests where steam is generated by heating water on the chest floor, and steam chests with hot water spray. In the latter system the steam is generated from water on the chest floor. The vat and chest systems are a classification made by Feihl and Godin (1975). The following description of each system is drawn from their report.

The water vat for submerged logs is a batch operation where logs are placed in an empty vat, weighted down, and immersed in water. If the water is kept circulating, vat temperature can be accurately controlled and logs evenly heated. A heat exchanger to heat vat water would allow a closed system if the vat water was re-used in another vat. The major disadvantages of this sytem are safety of operation, vat water must be drained to remove logs, and fresh logs may develop end splits if initial vat water is too hot.

The covered vat for floating logs is a continuous operation in which the logs are dumped into one end of a covered tank and conveyed by chains to the other end. The vat length is typically greater than 150 feet depending on the heating capacity required. If several vats are side by side, segregation by log diameter is possible for more efficient heating. This type of system is suitable only for floating logs; the hot water presents a safety hazard; the portion of the log not submerged may not heat and diameter sorting requires planning.

The uncovered vat for floating logs is basically the same as the one just described only the tank is not covered. Much more heat is lost to the surroundings with this system.

The steam chest is a chamber in which logs are piled and then a hot saturated atmosphere is created in the chamber. The atmosphere is obtained by a direct injection of steam or by boiling water in a trough on the chest floor. Sometimes a circulating water system sprays hot water over the logs. This hot water is either steam condensate in a steam injection system or from the trough containing hot water. The advantages of the chests are less worker danger than hot water vats and easier material handling in and out of the vat. The water trough system presents little disposal problems as only small amounts of steam condensate is produced. Disadvantages are batch operation and the water trough chests sometimes experience poor heating medium circulation.

Given a well-maintained chest or a total immersion vat system with good circulation of the heating medium, heating times are reported to be equal. It is suggested that since the blocks are not totally surrounded by the heating medium, floating blocks may require more time to heat. The heating time difference (over 40 percent for some combinations of log diameter, initial log temperature, and heating medium temperature) is not a function of the heat transfer potential of the medium (water versus steam) but rather the area of the block exposed to the heating medium. Feihl and Godin (1975) present suggested heating times for each type of heating system.

All heating systems outlined face environmental laws that do not allow process water to be discharged into rivers and lakes. This must be considered in the heating system design.

Temperature Sensing at the Lathe

For this study, more detailed information about the block temperature along the radius was desired. The experiment was to test for veneer differences at various temperatures at the time of peeling. A measurement system that could continuously monitor block temperature was developed to measure temperature differences during peeling.

Infrared instruments can measure surface temperature without contacting the material by sensing the electromagnetic radiation emitting from that material. By sensing the radiation of a wavelength between 0.1 and 100 x 10^{-6} meters (thermal radiation region), the infrared instrument can determine the surface temperature of a substance (Welty *et al.*, 1976).

Theory of Operation

The infrared instrument senses very low radiant energy emissions. The energy emitted by a material (wood) is over a broad spectral range with the peak intensity shifting toward the high end of the near infrared spectrum (0.1 to 100 x 10^{-6} meters) as the absolute (-273^{o}C is absolute zero) temperature of the body decreases. To sense the lower temperatures, an infrared instrument must filter wavelengths of the 5 to 15 x 10^{-6} meter range. In this range of wavelengths, 300^{o}K (27^{o}C or 80^{o}F) is the temperature that causes a material to emit maximum energy.

A selective filter from 8 to 14 x 10^{-6} meters is required to decrease interference from the atmosphere and visible light sources (overhead lighting). A more complete discussion of radiant energy emission is given by Welty et al. (1976).

Emissivity is defined as the ratio of the total emissive power (total rate of thermal radiation emitted in all directions and wavelengths) of a surface to the total emissive power of an ideally radiating surface (black body) at the same temperature (Welty et al., 1976). A black body neither reflects nor emits thermal radiation. The black body would absorb all wavelengths including visible light. Its emissivity is one.

Emissivity is a surface property of a material and the amount of energy that is radiated from a material at a particular temperature is determined by the emissivity. An emissivity correcting factor on an infrared temperature sensing device allows compensation for varying surface properties of materials. Shiny metals, which reflect light and thermal radiation, deviate greatly from a black body, so a low emissivity would be expected. Smooth polished copper has an emissivity of 0.2, aluminum 0.05, stainless steel 0.10. Organic materials such as wool, cotton, flesh, rubber, and tar have an emissivity of about 1 (very little thermal radiation is reflected).

Application to Wood

Infrared measurement of the temperature of wood has been reported by Englund et al. (1970), Dokken et al. (1973), and Molinos (1974). Englund et al. found the emissivity of ponderosa pine to be very close to 0.90 for a temperature range of 110°F to 201°F and moisture contents of two to 200 percent. They concluded that the infrared sensor exhibits a degree of precision adequate for many wood industry applications. Dokken et al. (1973) measured the temperature of peeler blocks on the lathe by infrared sensing. They found that the temperature loss from a block from the time it was removed from the heating medium to when peeling was initiated was much greater than expected. Blocks were found to be approximately room temperature at the surface. Maximum temperature was reached as the block was peeled. Temperature decreases to the core were noted for large diameter blocks. They concluded the sensor was satisfactory for mill conditions. Molinos (1974) did not give temperature profiles because his data recording and system set-up prevented reproducable measurements.

III. INDUSTRIAL SURVEY

Introduction

A questionnaire was prepared to collect information concerning the practices of block preheating in the plywood industry. Responses were desired from mills that peeled softwoods regardless of their block heating practices. Differences in mill operations could then be quantified. The differences would assist in the experimental design and provide inputs necessary for the economic analysis. With the cooperation of the American Plywood Association (APA), questionnaires were sent to member mills. The questionnaire appears in Appendix C.

Results

The results of the questionnaire were disappointing because too many of the respondents failed to quantify their answers. Few mills that did not heat softwoods prior to peeling responded so the differences in operating costs between heated and unheated mills could not be measured. The failure of the questionnaire to obtain the desired quantified answers was most probably due to poor questionnaire design. A telephone survey of the respondents might have been more successful in obtaining quantified answers.

Of the 21 mills that preheated, five used continuous hot water vats, 17 used steam chests, and one plant had both systems. Eight of the steam chests had a water spray while nine injected steam only.

Most respondents acknowledged the benefits of preheating given in the introduction. Improved veneer yields were cited by many mills (57 percent). The yield increases, however, fluctuated from five percent to

30 percent. The frequency and discrepancy between claims of veneer recovery increases as a result of preheating identified yield gains as an area of study.

The desired peel temperature for Douglas-fir ranged from 100° to $145^{\circ}F$. Lutz (1978) reports a desirable peel range of 60° to 140° for Douglas-fir. Table 2 reveals that the responses to actual block temperature at the lathe are subject to a wide range of opinion. The unclear response provided insight to develop the continuous block temperature monitoring system capable of controlling block heating if veneer recovery data and additional analysis proved the benefits of preheating.

Of the mills responding, 71 percent sorted peeler blocks prior to heating. The majority of those who sorted (52 percent) sorted by species. Classification by log diameter and grade were carried out by 43 percent and 29 percent of the mills that sorted, respectively.

It is difficult to draw conclusions about the heating cycles for each sorted class because the block diameter and initial block temperature were frequently not stated when giving heating times for the bolts. Charts used to calculate approximate heating times (MacLean, 1952; Fleisher, 1959; Feihl and Godin, 1975) are a function of block diameter and initial block temperature. The questions in this area should have been more specific to provide the desired information about heating practices.

The most useful information from the questionnaire was in providing cost estimates of yearly operating expenses of the vats. Parts of these data were incorporated into the economic analysis presented later. Pre-

Table 2. Results of Block Temperature Questions: All Species.

Location	Temperature, °F			
	Low	High	Mean	Std.
Desired at Core	100	140	111	14
Actual:				
Lathe	ambient	160	114	37
Round-Up	ambient	140	121	27
Core	ambient	140	112	14
Heating Medium	137	260	186	37

sentation of the responses, however, would create an unclear picture because of the different number of vats and/or chests used at each mill, and the accounting units differences among questionnaires make comparisons difficult. The questionniare should have asked for cost figures expressed in constant units.

To comply with future environmental regulations concerning discharge of heating water into rivers and lakes, mills that preheated were either constructing closed loop systems that recycled all water or, in a few cases, treating the heating water prior to discharge.

Improvements to existing heating systems desired by mill personnel included better medium circulation, reduced steam consumption, easier material handling, increased capacity, and conversion to a closed system to comply with discharge regulations.

IV. BLOCK HEATING SIMULATION

A knowledge of heating times necessary to obtain desired block temperatures prior to peeling for veneer led to an attempt to solve numerically a mathematical model that described heating rates for blocks and provided the resultant temperature distribution. Since the wood blocks are somewhat cylindrical and heating rates are desired, the partial differential equation for unsteady state heat flow for a cylinder seemed to be an appropriate model.

Model Description

Mathematical Model Formulation

For a homogeneous, isotropic material, the governing equation for unsteady state heat flow, in Cartesian coordinates, is

$$\frac{\delta T}{\delta t} = \alpha \left[\frac{\delta^2 T}{\delta x^2} + \frac{\delta^2 T}{\delta y^2} + \frac{\delta^2 T}{\delta z^2} \right] \qquad (1)$$

where

T = temperature

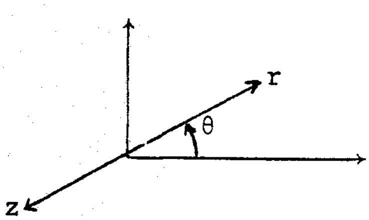
α = diffusivity

t = time

Transformed into cylindrical coordinates

$$\frac{\delta T}{\delta t} = \alpha \left[\frac{\delta^2 T}{\delta r^2} + \frac{1\delta^2 T}{r\delta r^2} + \frac{1\delta^2 T}{r^2 \delta \theta^2} + \frac{\delta^2 T}{\delta z^2} \right] \qquad (2)$$

where



The blocks are approximately eight feet long and no more than three feet in diameter. Theoretically, end effects can be ignored when the length of the cylinder is greater than 2 1/2 times the diameter. Equation 2 then reduces to

$$\frac{\delta T}{\delta t} = \alpha\left[\frac{\delta^2 T}{\delta r^2} + \frac{1\delta T}{r\delta r}\right] \qquad (3)$$

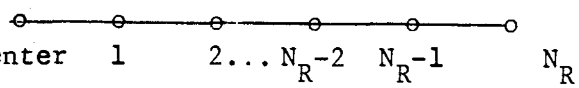
where

r = radius of the cylinder

This says that the temperature at any point in a transverse plane depends on the distance, r, of the point from the driving temperature difference.

State Equations

If a system of nodes is established along the radius of a cylinder,



and assume,

$$\left.\frac{\delta T}{\delta r}\right|_{r=0} = 0$$

the following system of equations will approximate equation 3 via a central difference scheme

$$\frac{d\tilde{T}_1}{dt} = \frac{\alpha}{\Delta r^2}\left[\frac{-4}{3}\tilde{T}_1 + \frac{4}{3}\tilde{T}_2\right] \qquad (4a)$$

$$\frac{d\tilde{T}_i}{dt} = \frac{\alpha}{\Delta r^2}\left[\frac{(2i-1)}{2i}\tilde{T}_{i-1} - 2\tilde{T}_i + \frac{(2i+1)}{2i}\tilde{T}_{i+1}\right] \qquad (4b)$$

$i = 2, 3, \ldots, N_R-2$

$$\frac{d\tilde{T}_i}{dt} = \frac{\alpha}{\Delta_r^2}\left[\frac{2N_R-3}{2(N_R-1)}\tilde{T}_{N_R-1} - 2\tilde{T}_{N_R-1} + \frac{2N_R-1}{2(N_R-1)}\tilde{T}_{out}\right] \qquad (4c)$$

$i = N_R-1$

with the temperature at the center being defined via the rule

$$T_o = \frac{4}{3}T_1 - \frac{1}{3}T_2$$

The initial temperature field condition is

$$T_i(0) = T_{in},\ i = 0, 1, 2, \ldots, N_R-1 \qquad (4d)$$

and

$$T_{N_R}(0) = T_{out}$$

where

$\tilde{T}_i$ = approximation of the temperature at node i,

$i = 0, 1, 2, \ldots, N_R-1, N_R$

T_{in} = initial temperature

T_{out} = medium temperature

Δr = distance between nodes.

It can be shown for an explicit computing (marching) scheme the stability condition is that

$$0 < \Delta t < \Delta r^2/2\alpha$$

where Δt = the time between approximations of the temperature.

A fourth order Runge-Kutha (RK-III) method was applied to solve the system of equations.

Program Description

The program to solve the system of equations was written in a structured programming language named FLECS. The language is an extension of FORTRAN IV. The program is self documenting. A listing can be found in Appendix D.

Inputs to the program establish values for the block, temperature, and run conditions. The block parameters are block radius and thermal diffusivity. The initial block temperature, the heating medium temperature, and final block temperature at a selected depth are required. Run conditions include the magnitude of the time step between approximations, the distance between nodes, and a time limit at which to terminate the run if the desired block termperature has not been reached. Also, a frequency of output for both the line printer and card punch may be given.

Program output consists of a summary of the input parameters, the final block conditions, and the total heating time. A table of block temperatures at each node at a given time is also produced. An example of the output is given in Appendix D. A data file can be punch coded and then read via a card reader into a Hewlett-Packard 9825 calculator. The calculator and a plotter then can generate plots of the temperature profile of blocks. The figures in this chapter were made in this manner.

Results and Discussion of Model Runs

Computational Experience

The program was run for numerous combinations of block, temperature, and run states. Aside from large values of the time step (greater than 3600 seconds) causing instabilty, the model appeared to be well behaved. As seen in Figures 1a and 1b, the rule that defined the temperature at the center, equation 4d, caused temperature values at the center to be below the initial block temperature. The error was never more than 1^{o}F and did not continue beyond 10 to 15 iterations when the time step was 300 seconds. This error was not thought to be significant.

Case Study Runs

Blocks of radii three (Figures 1a and 1b), six (Figures 2a and 2b), nine (Figures 3a and 3b), and twelve inches (Figures 4a and 4b) were heated in a medium at 180^{o}F. The initial block temperature was 70^{o}F and the desired final temperature two inches from the center was 120^{o}F for Figures 1a, 2a, 3a, and 4a. Figures 1b, 2b, 3b, and 4b represent temperature profiles when the final desired temperature was 140^{o}F. In each case, the time step was 300 seconds and one inch was the distance between the nodes. The thermal diffusivity was 0.000271 square inches per second as suggested by MacLean (1940) for green timbers. It was assumed that the outside of the block reached equilibrium with the medium instantaneously.

Figure 5 represents a temperature profile over time obtained when a six inch radius block was cooled from temperatures attained from heating a block to 120°F two inches from the center. The run was terminated when a point two inches from the center was 100°F. All other input parameters were held constant.

Discussion of Runs

Varying block radius and final designated temperature caused significant changes in the time necessary to obtain desired results. Increasing block radius, with a constant final desired temperature, caused an increase in the time necessary to reach that desired temperature (Figures 1a, 2a, 3a, 4a, and Figures 1b, 2b, 3b, 4b). For instance, to reach 100°F at the center of the block it required one hour for a three inch radius block, five hours for a six inch radius block, 11 hours for a nine inch radius block, and over 20 hours for a 12 inch radius block. This is an increase of time by a factor of seven for an increase in block radius of four times. This observation suggests that block segregation prior to heating would result in a more uniform temperature distribution between blocks for a given heating time and production cycle.

Within a block, the temperature at the nodes closest to the log surface quickly approach the temperature of the heating medium. As time increases, the rate of temperature increase decreases due to the smaller driving temperature gradient. Figures 4a and 4b at points 8 to 12 inches of radius illustrate this phenomenon.

A higher desired final temperature at a specified depth (Figures 1a and 1b, 2a and 2b, 3a and 3b, 4a and 4b) caused a greater percentage

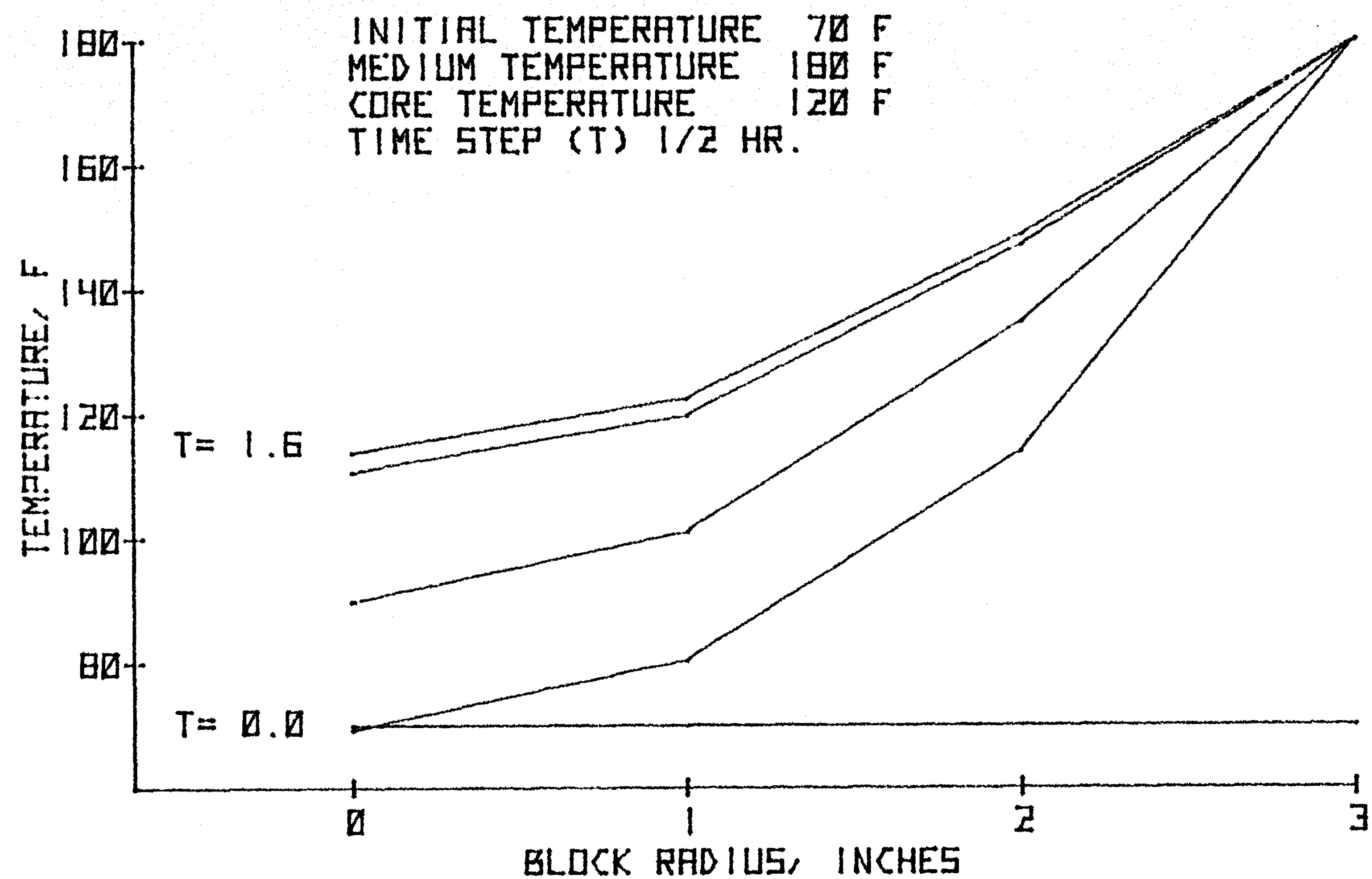


Figure 1a. Six Inch Diameter Block Heating Profile Over Time: 120°F Desired Two Inches from Center.

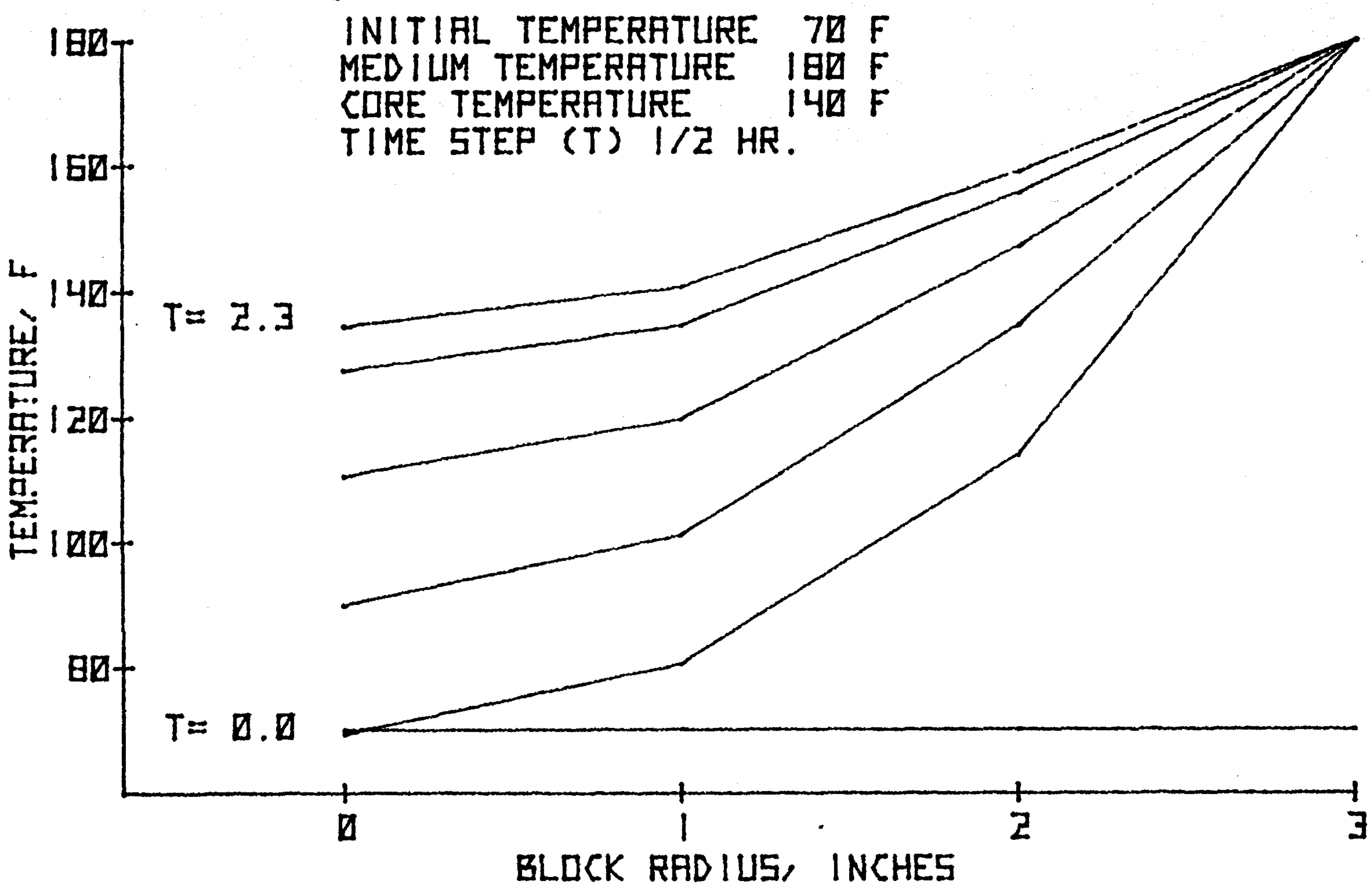


Figure 1b. Six Inch Diameter Block Heating Profile Over Time: 140°F Desired Two Inches from Center.

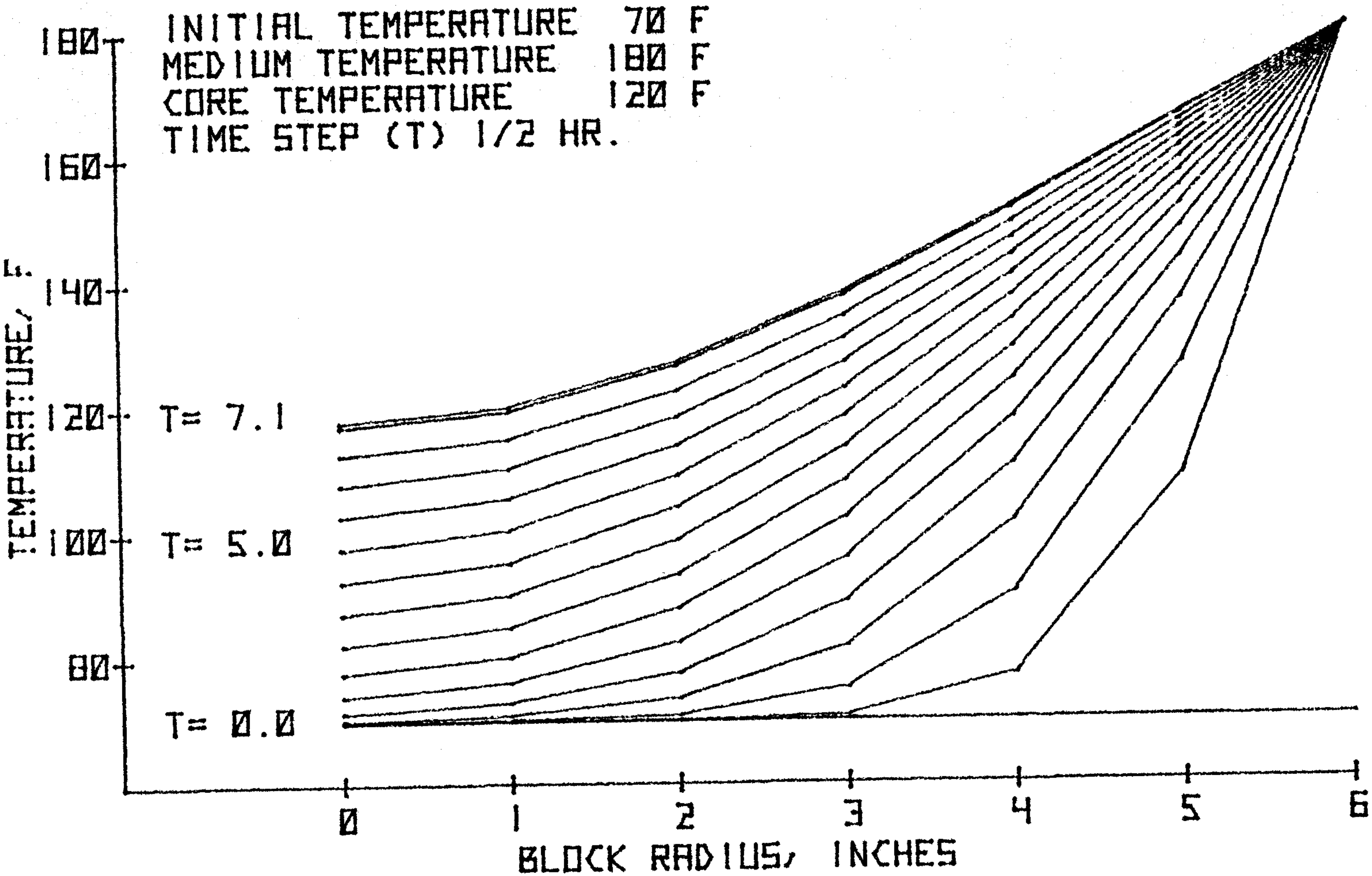


Figure 2a. Twelve Inch Diameter Block Heating Profile Over Time: 120°F Desired Two Inches from Center.

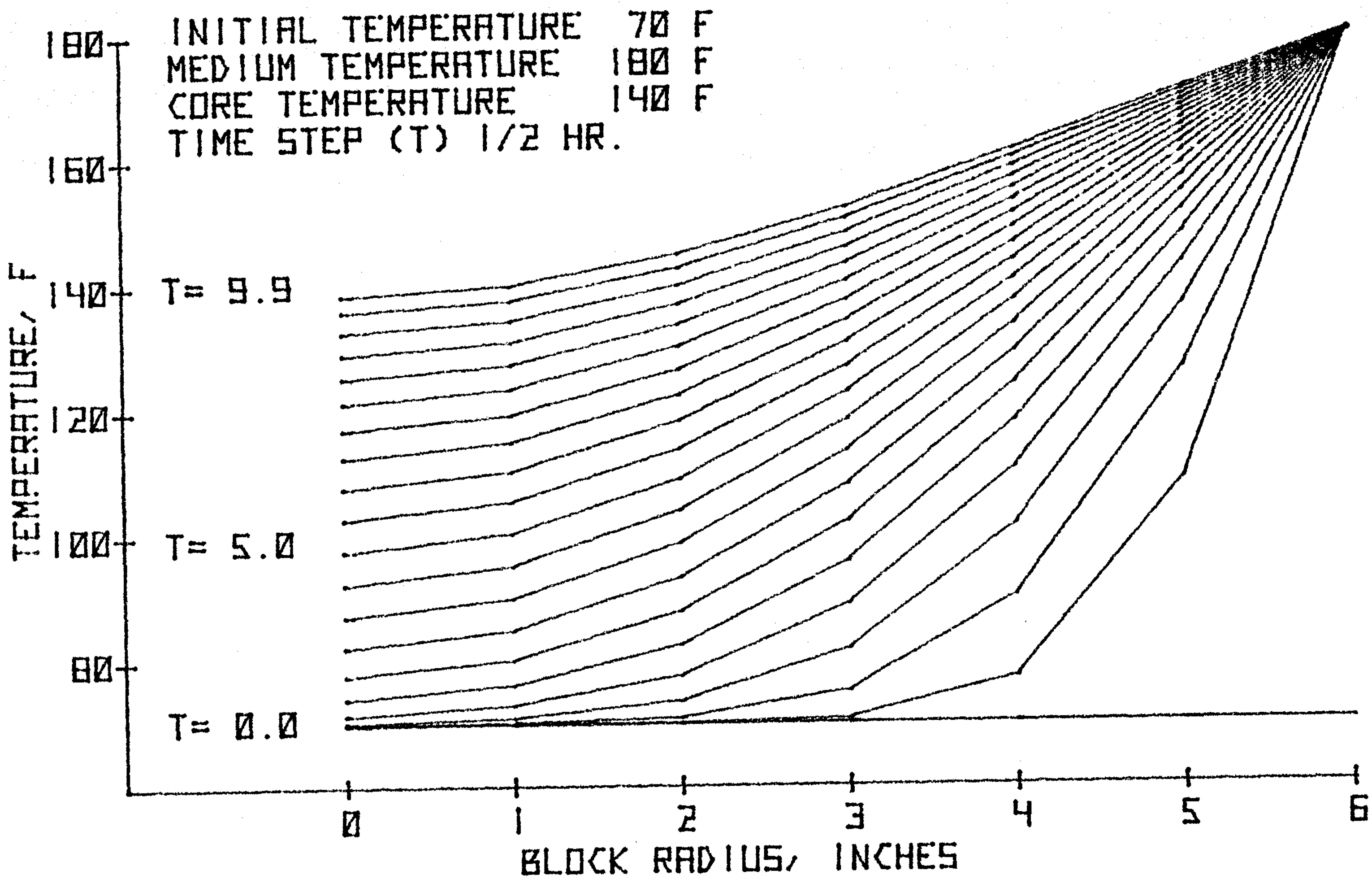


Figure 2b. Twelve Inch Diameter Block Heating Profile Over Time: 140°F Desired Two Inches from Center.

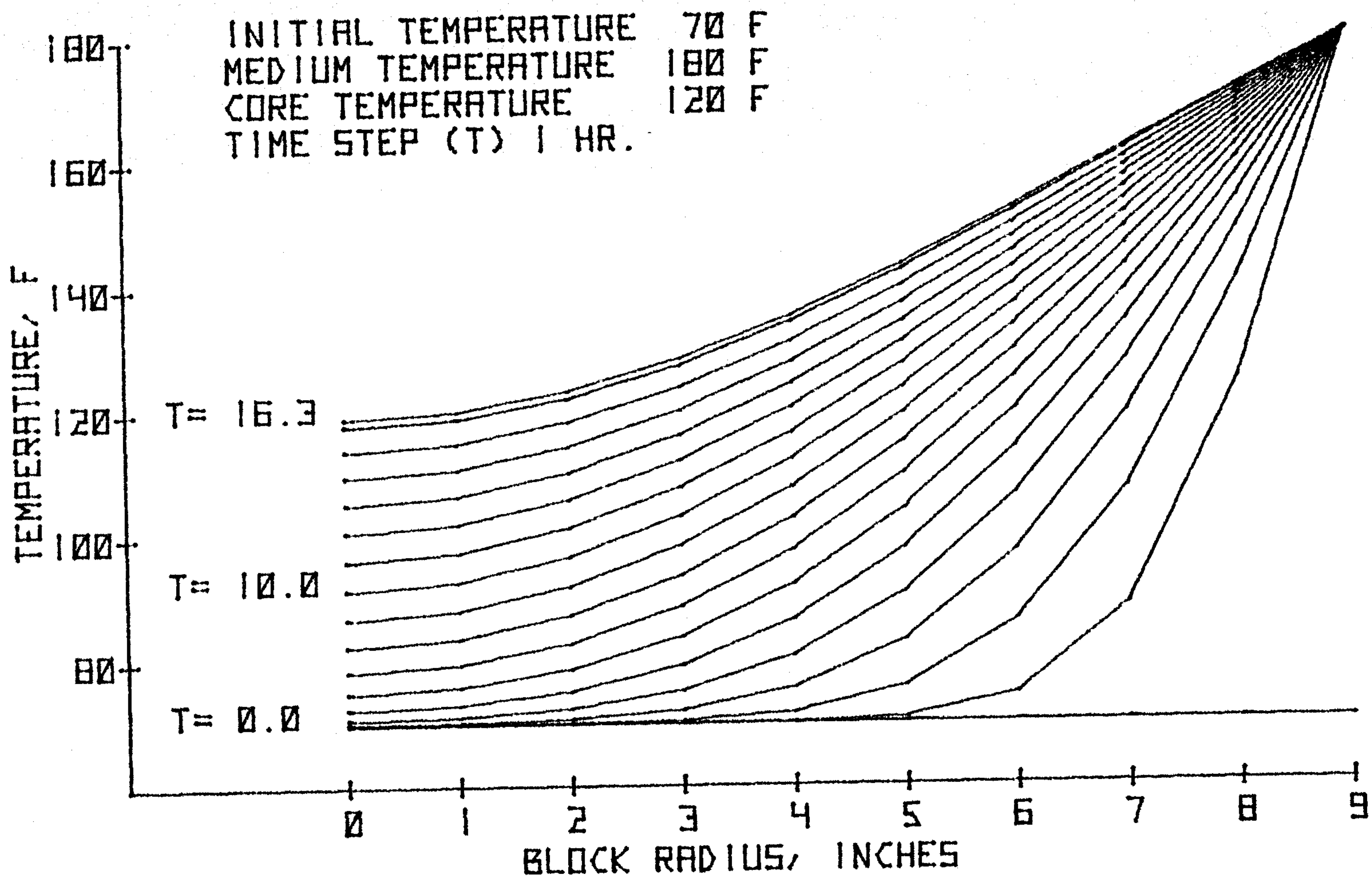


Figure 3a. Eighteen Inch Diameter Block Heating Profile Over Time: 120°F Desired Two Inches from Center.

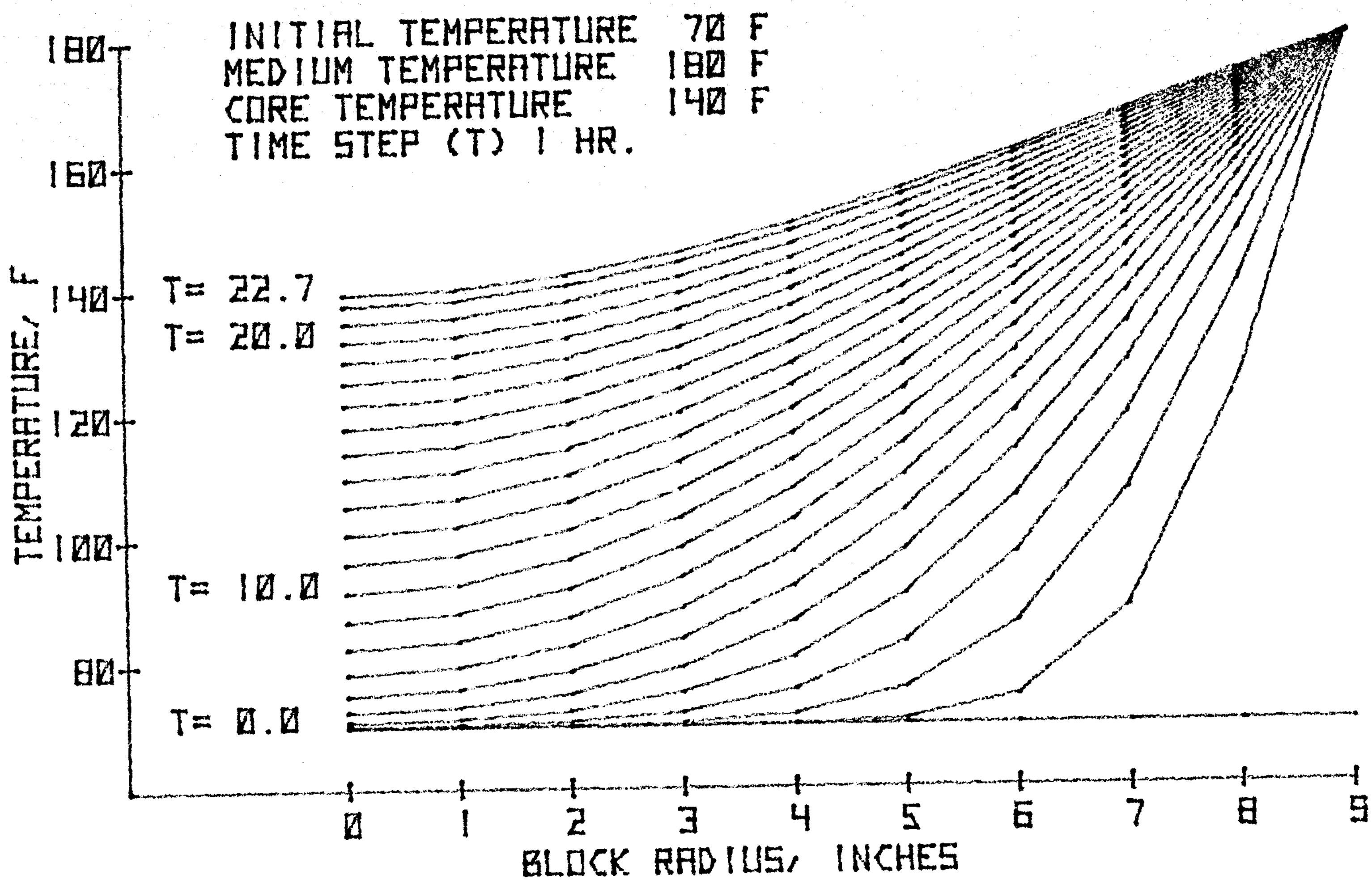


Figure 3b. Eighteen Inch Diameter Block Heating Profile Over Time: 140°F Desired Two Inches from Center.

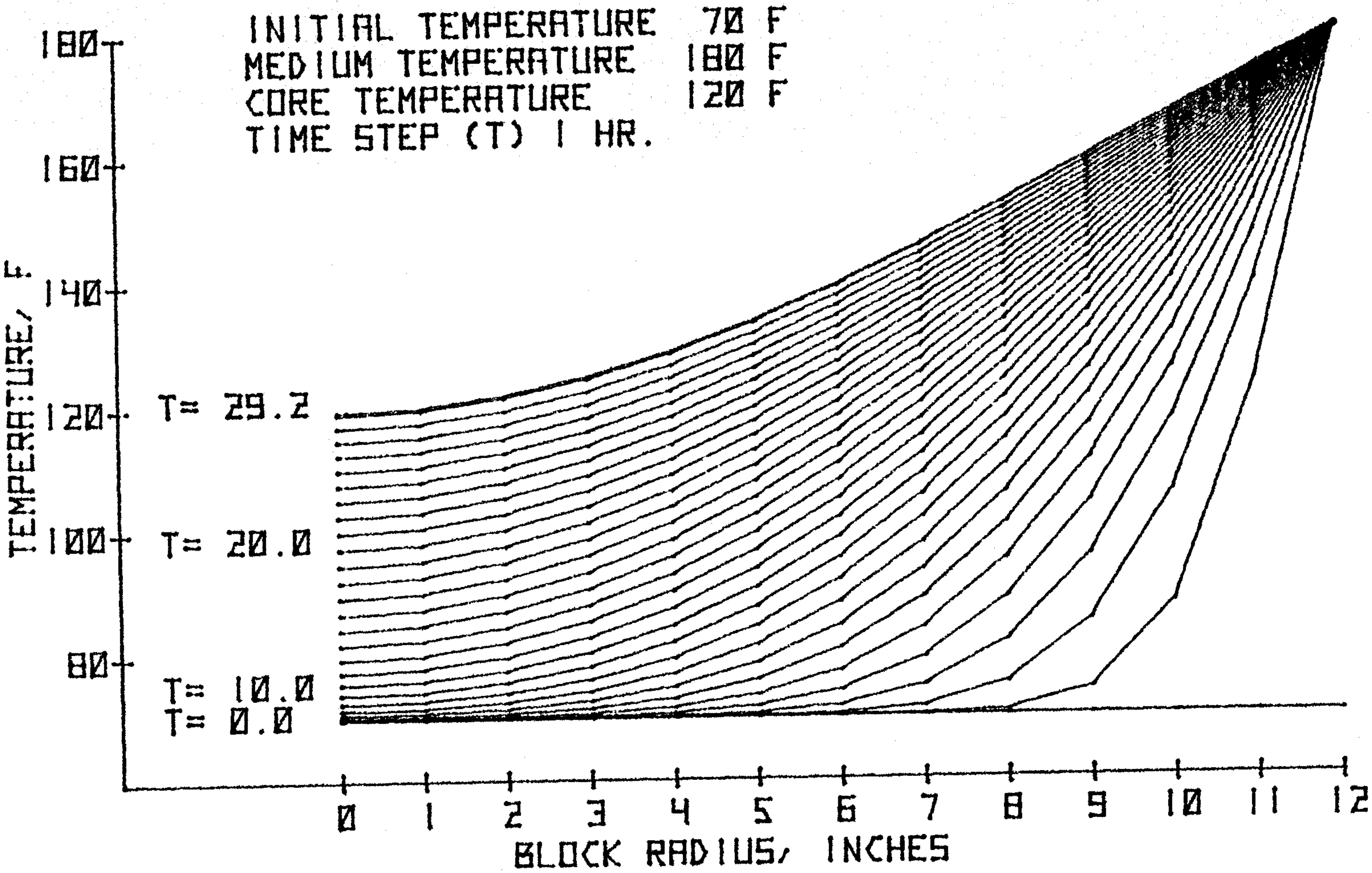


Figure 4a. Twenty-four Inch Diameter Block Heating Profile Over Time: 120°F Desired Two Inches from Center.

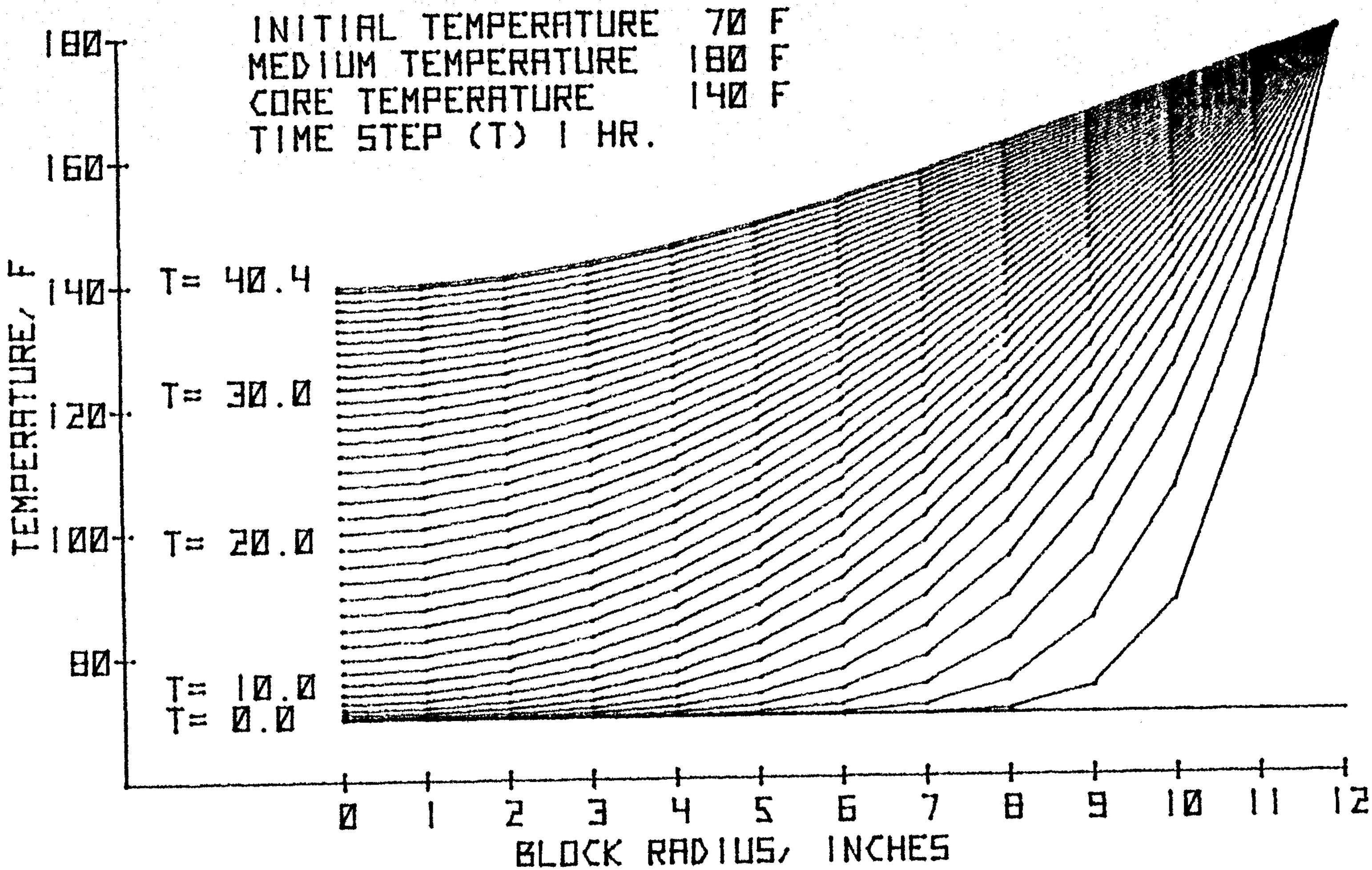


Figure 4b. Twenty-four Inch Diameter Block Heating Profile Over Time: 140°F Desired Two Inches from Center.

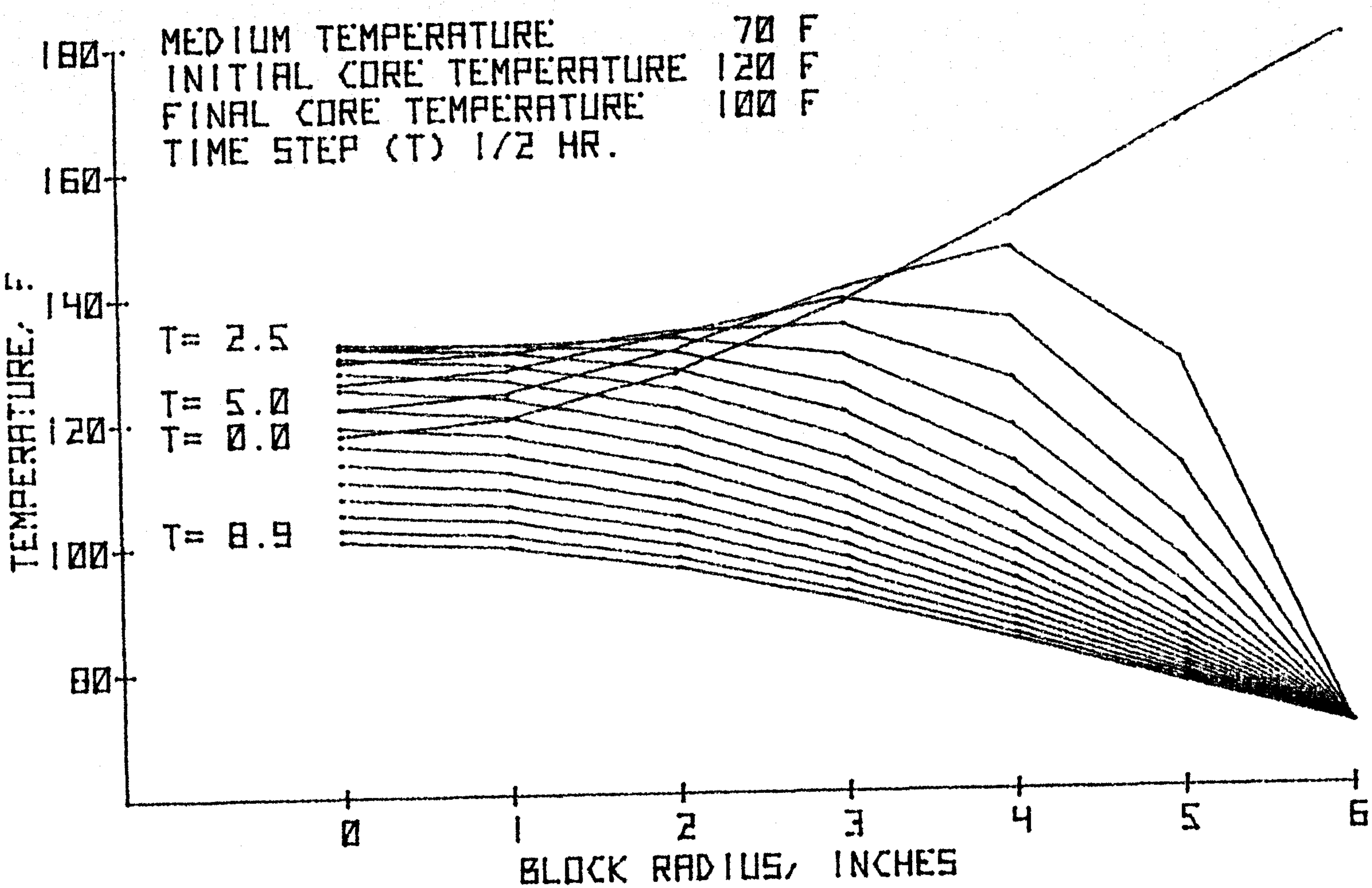


Figure 5. Twelve Inch Diameter Block Cooling Profile Over Time: 100°F Desired Two Inches from Center.

increase in heating time than the corresponding percentage increase in desired temperature. A greater heating time of about 40 percent resulted from a 17 percent increase in final desired temperature for all block sizes. The increased heating times would result in fewer blocks heated per unit of production time in an industrial environment. The incremental benefits of peeling at higher temperatures would have to be determined by a mill to give grounds for heating to those higher temperatures.

A temperature profile of a cooling block is depicted in Figure 5. The initial block temperature was generated by the program for a six inch radius block with a desired final temperature of 120^{o}F two inches from the center. The outside of the block was assumed to reach the medium temperature in the block interior continues to rise for some 2 1/2 hours. This is due to the initial temperature of the block being higher for the exterior than the interior. Eventually, as the time increases, the temperature over the entire block radius decreases. The temperature drop is substantial for the outside half of the block. This region represents the location of the higher quality wood material. If the benefits achieved by heating are dependent on the temperature of the block at the time of peeling, most benefits would be lost when the time delay between the end of heating and the initiation of peeling is sufficiently large. The magnitude at which the time delay becomes critical is not apparent from the figure.

Model vs. MacLean

Table 3 provides theoretical heating values derived utilizing the graphical methods presented by MacLean (1952) and theoretical heating values generated by the computer model. Calcuations are presented for 12, 18, and 24 inch blocks heated under the following conditions:

1) heating medium was steam at 180°F;

2) initial block temperature was 70°F;

3) thermal diffusivity was 0.000271 inches squared per second.

Examination of the block temperatures at a given time and point shows the block temperatures generated by each theoretical method are within 8°F or less. It should be noted that Table 3 is not an attempt to validate the model developed in this chapter. Rather, Table 3 merely illustrates that MacLean's graphical solution and the numerical approximation scheme employed by the computer arrive at nearly identical results. The similarity in results should not be surprising given both MacLean's graphical solution and the numerical approximation scheme solve the same governing equation under the same assumptions.

Applicability of the Model to Wood

When applying equation 1, its subsequent reductions, and the system of state equations (4) to unsteady state heat transfer in a material, two assumptions are necessary. First, the material is assumed to be homogeneous. Secondly, the material must be isotropic. Also to neglect heat transfer from the block (cylinder) ends, this heat flow must be negligible.

Homogeneity

A homogeneous material has a uniform structure. Wood possesses a nonuniform structure on the macroscopic and microscopic levels. Some of

Table 3. Theoretical Heating Temperatures: MacLean (1952) vs Baskin

Starting Temperature: 70°F Diffusivity: 0.000271 in^2/second
Heating Medium Temperature: 180°F
Heating Medium: Steam

12 Inch Block

Distance From Surface

Time	6 inches MacLean	6 inches Baskin	6 inches MacLean	6 inches Baskin
1 hr.	78°F	73°F	70°F	70°F
2	90	88	72	70
3	104	98	76	74
5	126	122	90	87
10	158	150	148	138

18 Inch Diameter

Distance From Surface

Time	9 inches MacLean	9 inches Baskin	9 inches MacLean	9 inches Baskin	9 inches MacLean	9 inches Baskin
2 hrs.	93°F	86°F	71°F	72°F	70°F	72°F
5	119	113	84	77	74	73
10	138	130	104	102	94	92
15	152	145	128	120	125	122
20	160	157	144	138	138	130

Table 3. Theoretical Heating Temperatures: MacLean (1952) vs Baskin

24 Inch Diameter Block

Distance From Surface

Time	12 inches MacLean	Baskin	12 inches MacLean	Baskin
5 hrs.	114°F	110°F	80°F	77°F
10	135	132	98	93
20	154	148	128	122
30	162	158	145	140
40	168	162	156	152

Time	12 inches MacLean	Baskin	12 inches MacLean	Baskin
5 hrs.	70°F	70°F	70°F	70°F
10	78	77	76	75
20	110	103	104	97
30	132	127	130	121
40	146	143	144	140

the macroscopic interfaces in wood are the earlywood-latewood, and the sapwood-heartwood-juvenile wood transitions. Cell types, cell wall layers, the cell lumen, and the cell structure itself are some other macroscopic discontinuities. In general, wood is microscopically composed of chemicals that are not uniform in size, structure or distribution. For example, Douglas-fir is composed of 67 percent holocellulose, 27 percent lignin and 6 percent secondary material (tannins, oils, resins, gums and ash). (Pashin and deZeeuw, 1970). In equation 1, there are no terms which account for the differences in heat transfer that would occur when dissimilar materials are involved.

Anisotropic Nature of Wood

The second assumption needed to state the equations is that the material be isotropic, i.e., equal properties in all directions. This assumption allows the diffusivity to be independent of the direction of heat flow. Wood is an anisotropic material. The rate of heat flow would not be expected to be independent of direction.

Diffusivity is defined as the change of temperature in a unit of volume of substance by the amount of heat that flows through a unit area of unit thickness and having a unit difference of temperature between the faces. Symbolically

$$\alpha = \frac{k}{c\rho} \tag{5}$$

where

α = diffusivity

K = thermal conductivity

C = specific heat

ρ = density.

The effect of flow direction on the diffusivity of wood was addressed by MacLean (1930, 1932). He recognized that wood was not an isotropic material when solving equation 1 to obtain heating times for wood. Inserting terms for the radial and tangential diffusivity into equation 1, MacLean experimentally determined values for radial and tangential diffusivity for the species studied. Heating times for wood were calculated using an overall transverse diffusivity of 0.000271 square inches per second. Fleischer (1959) relies quite heavily on MacLean's work when he recommends heating times for logs, bolts, and flitches to be cut into veneer. Their studies conclude that the difference between the radial and tangential diffusivity is small and an overall transverse diffusivity yields reasonable results.

Temperature Effect on Diffusivity

To expect a varying diffusivity with temperature, one or more components of diffusivity would have to change with temperature. From the symbolic relationship, equation 5, it can be seen that diffusivity is directly proportional to the thermal conductivity and inversely proportional to the specific heat of the material. Ward and Skaar (1963) report that there is an increase with temperature of both specific heat and thermal conductivity of wood based material in accordance with the results based on heat theory for crystalline organic solids. For modeling unsteady state heat flow, where time to reach a certain temperature is the desired result, assumption of constant diffusivity with temperature may not be correct.

End Effects

To reduce equation 1 to the form used for the state equations, the end heating effects are ignored. MacLean (1952) reported that the longitudinal diffusivity of wood is 2 1/2 times the transverse diffusivity. Heat transfer along the length of the block would be expected to be more than twice the rate of that along the radius. Assuming an infinitely long cylinder to model a wood block may not be correct

Conclusions

The model for unsteady state heat transfer for a cylinder may not be an appropriate model for wood when constrained by constant diffusivity and homogeneity. The diffusivity of wood is reported not to be constant over temperature or direction of flow. Wood is a heterogeneous material with complex chemical structure that prevents continuous flow paths. The simplifications of the problem allowed the equation to be solved. The results obtained were not wholly unreasonable but to develop more precise heating times for blocks, a more realistic model may be necessary. To derive an accurate dynamic mathematical model of heat transfer in wood, it may be necessary to consider changing diffusivity and discontinuities.

In Chapter 6, Table 7 presents actual block temperatures obtained during heating and theoretical block temperatures as derived by MacLean (1952).

V. DATA ACQUISITION SYSTEM

Background

It was thought that block temperature at the time of peeling could be a critical factor that greatly influenced veneer yield and peel quality. If studies were to be made on yield and peel quality involving various peeling temperatures, an accurate, reproducable measurement system would be needed to monitor block temperature. Also, if temperature at time of peeling did prove to be important, an automatic monitoring and control system of block temperatures could be of great value to the industry.

Utilizing a non-contact temperature sensing device and a microprocessor as a controller, the author developed a continuous block temperature monitoring system for use at the lathe.

System Description

The block temperature monitoring system consisted of a broad band, low temperature non-contact sensing device (infrared), a potentiometer, two analog-to-digital (A/D) converters, an INTEL® SDK-80 single board microcomputer, and a Hewlett-Packard 9825A desk-top calculator.

Temperature Sensing Device

The non-contact optical temperature sensing head was manufactured by the E^2 Thermodot Company, of Carpenteria, California. The model number is Nova Model TD-22. The Nova is a broadband, low temperature, large field of view instrument. Temperature range for the instrument is 32 to $400^{\circ}F$, calibrated to $\pm 2^{\circ}F$ from 85 to $160^{\circ}F$ and $\pm 4^{\circ}F$ over the entire range. The target size (field of view) is defined by the formula:

$$\text{Diameter of target} = \frac{\text{Distance}}{15}$$

The spectral range of the instrument is 8 to 14 microns, which reduces atmospheric and steam vapor effects on the temperature sensed from the desired target.

The sensing head controller is housed in a rack mount cabinet in which the operating controls and digital readout of temperature are located. A 0 to 10 volt output linear with temperature is available on a terminal strip located at the rear of the controller. Complete specifications can be found in Table 4. The factory-supplied calibration information is given in Figure 6.

Lathe-Knife Position Sensor

A ten-turn bushing mount potentiometer was used to monitor lathe-knife position. Positioned in a cam-controller for the lathe, the potentiometer produced a voltage output linear with knife position. The linearity was 0.20 percent. Together with the temperature sensing head, the potentiometer output provided a temperature at a known depth of peel as well as block diameter after round-up and core size.

Analog-to-Digital Conversion

An analog-to-digital (A/D) converter accepts an analog input (continuous electrical signal, eg. voltage) and transforms that input to discrete digital form. The digital output of the A/D converter can then be input to a computer, digital controller, or digital data logger.

Table 4. Infrared Temperature Sensor Specifications.

Temperature range	32 to 400°F
Three digit panel meter readout	
Recorder output	0-10 V
Response time (to 99%)	0.5 sec
Accuracy	±2°F between 85 and 160°F ±4°F between 32 and 400°F
Sensitivity	±.2% full scale
Repeatability	±0.5% full scale range, long term
Spectral range	8-14 μ
Emittance	0.1 to 1.0
Target distance	8" to infinity
Target size	distance/15 beyond 15"
Power requirements	115 V, 60 Hz, 7 watts

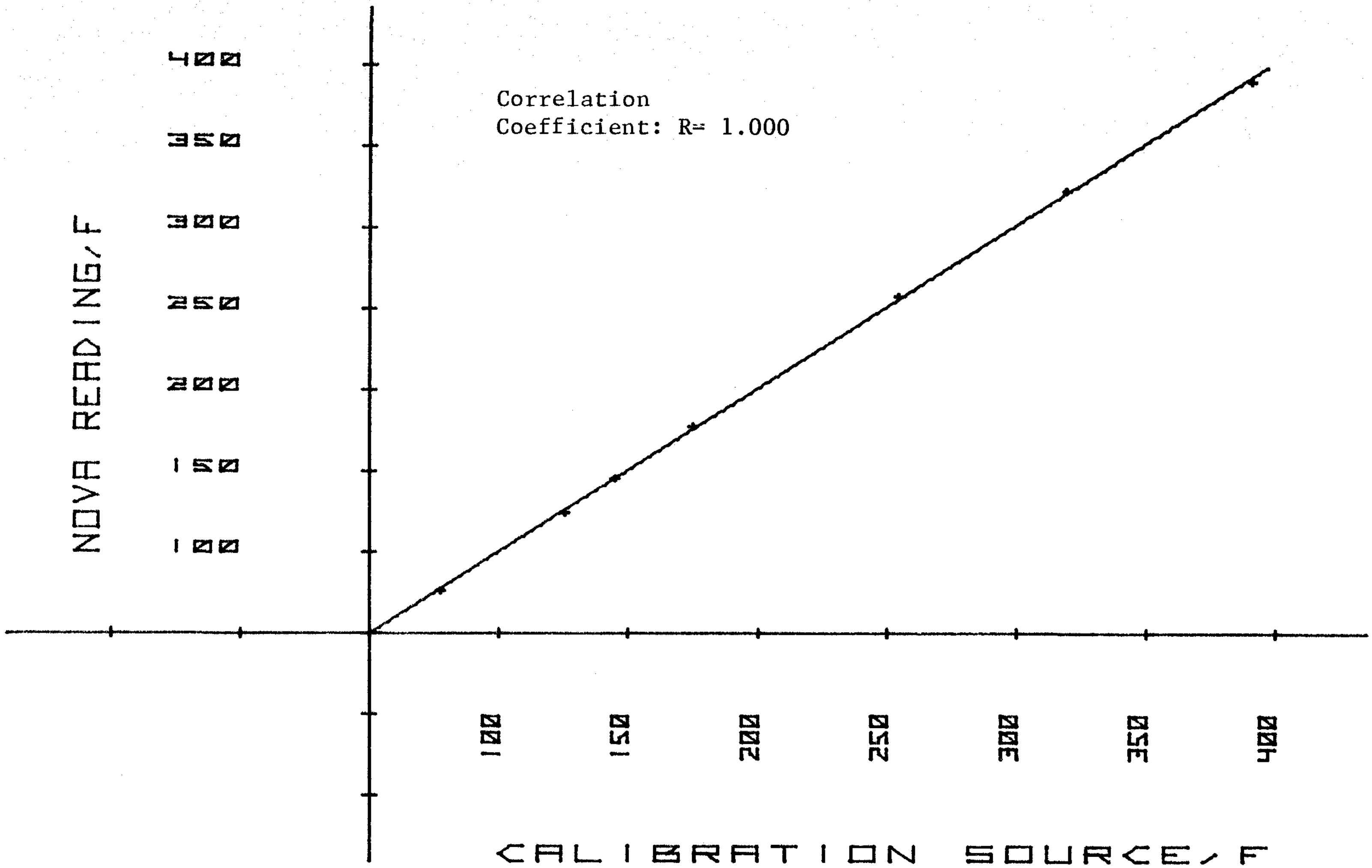


Figure 6. Infrared Temperature Sensor Calibration Curve.

The temperature of the block at a point as indicated by the analog (voltage) levels of the temperature sensing head and the knife-position potentiometer, was fed to the A/D converter and then into the microcomputer for further processing.

The A/D converter was designed, built and tested by the author. Calibration tests of the system showed accuracy and linearity of the sensing devices was not impaired by the converters. Figures 7 and 8 show calibration curves over the converters' range.

Microcomputer

The INTEL® SDK-80 single board microcomputer is an inexpensive (less than $750) computer capable of process monitoring, control, and data logging if configured and programmed appropriately.

The microcomputer's roles in the system were to control the rate and duration of data collection, store data from the A/D converters, and transmit the data to the Hewlett-Packard.

Sensing a signal corresponding to the lathe's "cap" closing, the microcomputer collected the temperature-distance data five times per second until core kickout was detected. For a 12 inch, 18 inch, and 24 inch diameter block, approximately 100, 166 and 220 data sets, respectively, were collected per block.

Hewlett-Packard 9825A

The Hewlett-Packard (HP) 9825A desktop calculator is actually a small computer with a high level language, advanced input/output capabilities, and a magnetic tape storage system. All of these features were exploited when interfacing the SDK-80 microcomputer.

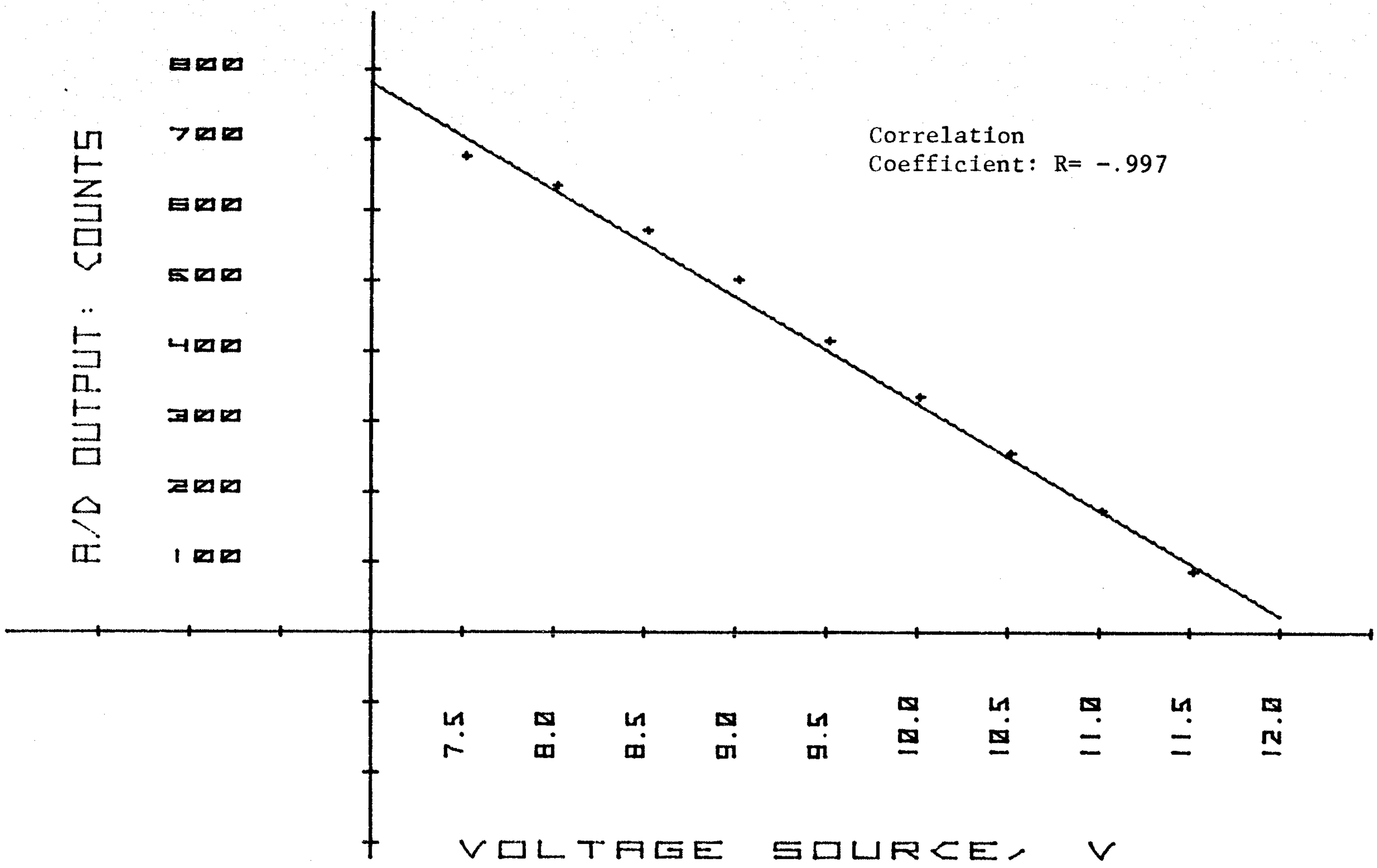


Figure 7. Analog-to-Digital Converter Calibration Curve: Circuit 1.

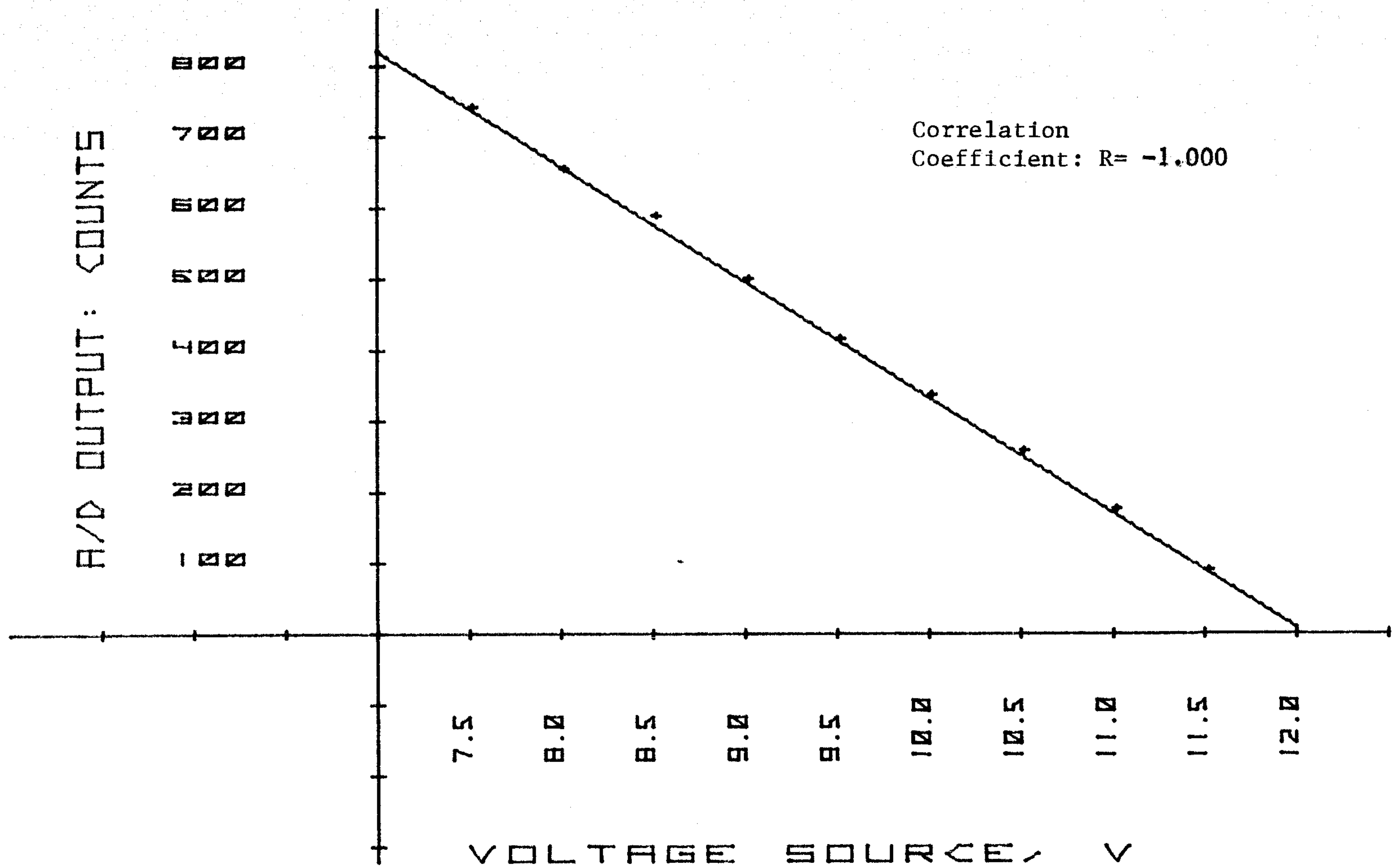


Figure 8. Analog-to-Digital Converter Calibration Curve: Circuit 2.

The HP was programmed to accept data from the microcomptuer, perform manipulations on the data, and then at the end of peel, store the data for that block on tape. A new collection cycle was initiated after storage to maintain data integrity.

The HP also served as a controller for the microcomputer. The microcomputer programs for data acquisition, program editing capabilities, and system calibration programs were stored on magnetic tape. Capabilities were also developed so the HP could transfer the stored data to a larger computer where computations beyond the range of the microcomputer or HP could be carried out.

VI. VENEER RECOVERY STUDY

The objective of the veneer recovery study was to quantify the volume, grade, and veneer item (sheet width) recovery from low grade second growth Douglas-fir blocks peeled heated and unheated. Three diameter groupings of 12, 18, and 24 inches were chosen. There were three treatment temperatures of 140°F and 120°F at the core and ambient temperature.

Experimental Design

Veneer Yield

The quantative difference between treatments and diameters were to be measured veneer volume per cubic foot of block volume for total, grade, and sheet type recovery.

The three treatments and three diameters resulted in a 3 x 3 design matrix. In each of the nine matrix cells three blocks were peeled to provide an estimate of the mean for that cell for each recovery variable. Realizing that both the wood and industrial processes are variable, a replication of the 3 x 3 matrix was performed on three successive days. On any one day 27 blocks were peeled; 81 blocks were peeled overall.

The ANOVA table and associated degrees of freedom are presented in Table 5. Via an F-statistic, differences between the main sources (treatment and diameter) and interactions (treatement * diameter) were tested for significance.

Table 5. ANOVA Table for Analysis of Veneer Recovery Study (Kempthorne, 1952).

Source	df	Sum of Squares
Replication (Days) R	r-1	$\sum_i \frac{Y^2_{i..}}{ts} - \frac{Y^2_{...}}{rts}$
Treatments T	t-1	$\sum_j \frac{Y^2_{.j.}}{rs} - \frac{Y^2_{...}}{rts}$
Error (a)	(r-1)(t-1)	$\sum_{ij} \frac{Y^2_{ij.}}{s} - \sum_i \frac{Y^2_{i..}}{ts} - \sum_j \frac{Y^2_{.j.}}{rs} + \frac{Y^2_{...}}{rts}$
Diameter S	s-1	$\sum_k \frac{Y^2_{..k}}{rt} - \frac{Y^2_{...}}{rts}$
Diameter * Treatment	(t-1)(s-1)	$\sum_{jk} \frac{Y^2_{..k}}{r} - \sum_j \frac{Y^2_{.j.}}{rs} - \sum_k \frac{Y^2_{..k}}{rt} + \frac{Y^2_{...}}{rts}$
Error (b)	(r-1)t(s-1)	By subtraction
Total	rts-1	$\sum_{ijk} Y^2_{ijk} - \frac{Y^2_{...}}{rts}$

where:

replicate number= $i = 1,2, \ldots, r$

treatment number= $j = 1,2, \ldots, t$

diameter number= $k = 1,2, \ldots, s$

mean value = Y

Veneer Thickness

Of the three veneer quality standards set forth by Hailey and Hancock (1973), veneer thickness was deemed the only component of veneer quality that could be measured in quantitative terms relating directly to economic units. If peel tolerances can be controlled to save one thousandth of an inch of veneer, a savings of at least $25,000 annually can be realized (Hancock, 1977).

The sampling plan for thickness was to measure to the nearest 0.001 inch on the right, middle, and left third sections of four random width sheets of veneer from each block peeled. The mean of the 12 readings was then averaged over the three blocks in each cell of the 3 x 3 design matrix and analyzed via the already designated ANOVA table.

Study Procedures

Production Facilties

The cooperating mill was Sun Veneer, Inc., of Roseburg, Oregon. Its primary product is green veneer suitable for use in construction grade plywood. The predominant species peeled is Douglas-fir logged from the Coast and Cascade Ranges. The green-end equipment consisted of a geometric centering, automatic charger, eight-foot lathe with six trays, two automatic clippers, and a fishtail saw (fishtail veneer was cut to produce stock for stitching veneer to make full sheets).

The block heating equipment consisted of ten steam chests (vats), 10 feet by 12 feet by 80 feet, with counterweighted overhead doors. Live steam was injected through two pipes running the length of the vat floor. Foxboro controllers were capable of maintaining a temperature of up to 220°F in each vat. Ultimately the highest vat temperature was determined by the steam pressure delivered by the mill power plant.

Block Selection and Preparation

The blocks to be peeled were selected from the cold deck already debarked and bucked to a nominal 103.5 inch length. All blocks were Douglas-fir No. 3 Sawmill logs as determined by the mill yard scaler. The selection criterion for a block was a nearly concentric block for either the 12, 18, or 24 inch diameter class. The blocks appeared to be sound throughout. Each block selected was measured for volume to the nearest 0.01 foot and marked for a treatment and diameter for later identification.

Treatment Temperatures

The study design called for core (two inches from the block center) temperatures of 140°F for one treatment and 120°F for the other heated treatement. These temperatures were not attained.

Mill production schedules would not allow the two vats necessary to attain the desired treatment temperatures to be taken out of production for more than one ten hour shift. It was anticipated that the 24 inch diameter blocks would not reach the desired core temperature in ten hours. Therefore, all blocks were heated for the same nine hour period. The treatment (temperature) differences were attained by allowing one group of blocks (three 12, 18, and 24 inch blocks) to cool longer than another group of blocks. Temperatures of the blocks were recorded at the lathe to quantify treatment differences.

The three treatments became a "hot" treatment (20 minutes out of vat before peeling), a "warm" treatment (50 minutes out of vat before peeling) and a "cold" treatment (peeled unheated).

Throughout the remainder of the paper, treatment 1, Vat 1, or "hot" treatment will refer to those blocks cooled 20 minutes prior to peeling. Treatment 2, vat 2, or "warm" treatment will refer to those blocks cooled 50 minutes prior to peeling. Treatment 3, or "cold" treatment will refer to those blocks peeled unheated.

Veneer Production

The blocks were peeled on three consecutive days during the mill's scheduled maintenance time. The spur knives were set to 101.5 inches and the blocks were peeled to a nominal 4.50 inch core. Veneer was identified by treatment and diameter by a color coding system.

After heating, all blocks were placed on the lathe-infeed deck by treatment grouping (three 12 inch, three 18 inch, and three 24 inch blocks) of hot, warm, and cold.

Prior to peeling, a freshly sharpened knife was installed, and set by the lathe operator. The lathe settings are detailed in Table 6. The lathe and clippers were not reset for peeling the cold blocks. Blocks were peeled to 1/10 inch thick veneer. The veneer was clipped to recover the optimum value of each log within the cooperating mill's normal manufacturing procedures.

Veneer Tally

Each piece of veneer was individually tallied by day, treatment, and diameter. All veneer was sorted into full and half sheets, random widths, and fishtails on the green chain.

Veneer Grading

Green veneer was graded by company graders the day after peeling. An attempt was made to separate into four grades, A, B, C, and D, as described in P.S. 1-74[1]. However, mill practice was to separate into three market grades of green veneer, AB, CD, and Utility, as reported by the weekly newsletters Crow's and Random Lengths. The full and half sheet grading became A, AB, C, CD and Utility. The grade separation into the APA standards was not consistent from day to day.

The random lengths and fishtails were separated into A,CD, and Utility grades. Each piece was measured for width to the nearest 0.01 foot. The fishtails were assumed to be a nominal 36 inches long.

Data Compilation and Statistics

Recovery data were compiled by computer programs written by the author to provide recovery for each block by grade and veneer item. The units produced were volume on 3/8 inch basis and percent veneer recovered per cubic foot of block. The grades A, AB, B, C, CD, and Utility were then combined to AB (A and AB), CD (B, C, and CD), and Utility to give veneer recovery in the market grades for green veneer.

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1 American Plywood Association. U.S. Product Standard P.S. 1-74 for construction and industrial plywood with typical APA grade-trademarks. 35 p. 1974.

Table 6. Lathe Specifications: 0.1 Inch Douglas-fir Green Veneer, 81 Bolt Sample.

Lathe Model: COE 249
Swing: 65 inches
Length: 101.5 inches

Horizontal gap	0.098"
Vertical gap	0.092"
Veneer thickness	0.100"
Nosebar type	Double roller-bar
Roller Diameter	5/8"
Knife thickness	5/8"
Rockwell hardness	58
Main bevel	23.5°
Micro bevel	none
Concavity	0.001"
Cutting angle (at 14")	90°

The block volume was based on the average diameter to 0.01 foot on both ends and the nominal length of 101.5 inches (spur knife distance) of the debarked bucked blocks. The volume was computed by the following formula:

$$\text{Gross Cubic Volume} = \frac{L(D_S^2 + D_L^2)}{12 \cdot 4 \cdot 2}$$

where

D_S = average diameter small end

D_L = average diameter large end

L = length of block (101.5 inches)

Veneer and reject volume 3/8 inch basis is based on the green untrimmed grade and reject veneer.

The statistics were performed using the Statistical Analysis System (SAS) on an IBM 370/168 Model 1 computer located at the Environmental Protection Agency's (EPA) Washington Computer Center (WCC). Access to the WCC was via a remote job entry terminal (RJE) located at the EPA facility in Corvallis, Oregon.

Data Acquisition System Performance

The data acquisition system successfully recorded 52 of 54 heated block temperature profiles. The potentiometer monitoring lathe-knife position, however, did not perform satisfactorily due to friction losses when knife direction was changed rapidly. Also, increased reliability of the data acquisition system could be gained by improvement of the communication protocol between the microcomputer and the HP. This would eliminate cause of the loss of the two temperature profiles.

The infrared temperature sensing head (Nova) was located three feet behind, four feet above, and one foot from the block center. From this location, a clear, unobstructed view of the veneer ribbon was possible. Also, the sensing head was somewhat protected by the lathe-works from wood debris and accidents. Little or no water vapor was present.

Although the lathe-knife position readings were not reliable, temperature versus elapsed time of peel can be compared. Representative block temperature profiles as monitored at the lathe are given in Figures 13, 14, and 15 for each study treatment and block diameter. These profiles were selected because the time of peel was approximately equal in each diameter class, and the profiles can be compared to temperature distributions recorded during heating as indicated by thermocouple measurement. The heating profiles are given in Figures 9 through 12. Both sets of data (thermocouple and Nova readings) were collected on the same day.

Block Heating Profiles

A separate vat (chest) was used for each treatment. Both vats' temperatures were set via a Foxboro controller to reach 180°F.

Thermocouple Measurement System. The block temperature heating profiles were obtained via an Esterline Angus multipoint recorder (Model No. E1124E). Iron-constantan (Type J, 32-600°F range) thermocouples were placed inside one block per diameter class and heat treatment at the depth and frequency as indicated on the diagrams of block heating. To reduce measurement error (Steinhagen, 1977) thin (24 gauge, 0.002 inch thick) teflon insulated thermocouple wire was used. Small holes,

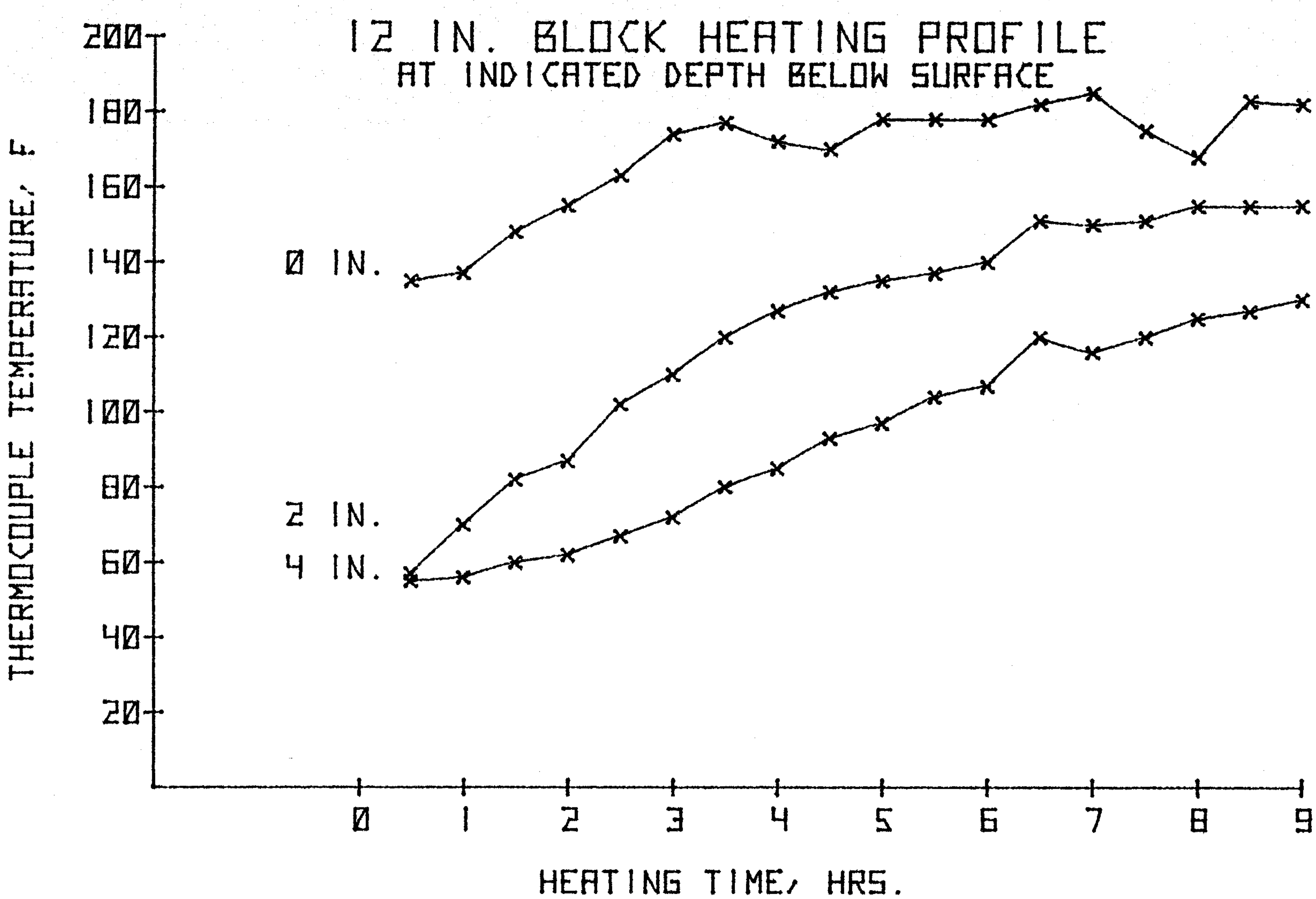


Figure 9. Twelve Inch Diameter Block Heating Profile from Treatment (Vat) 1.

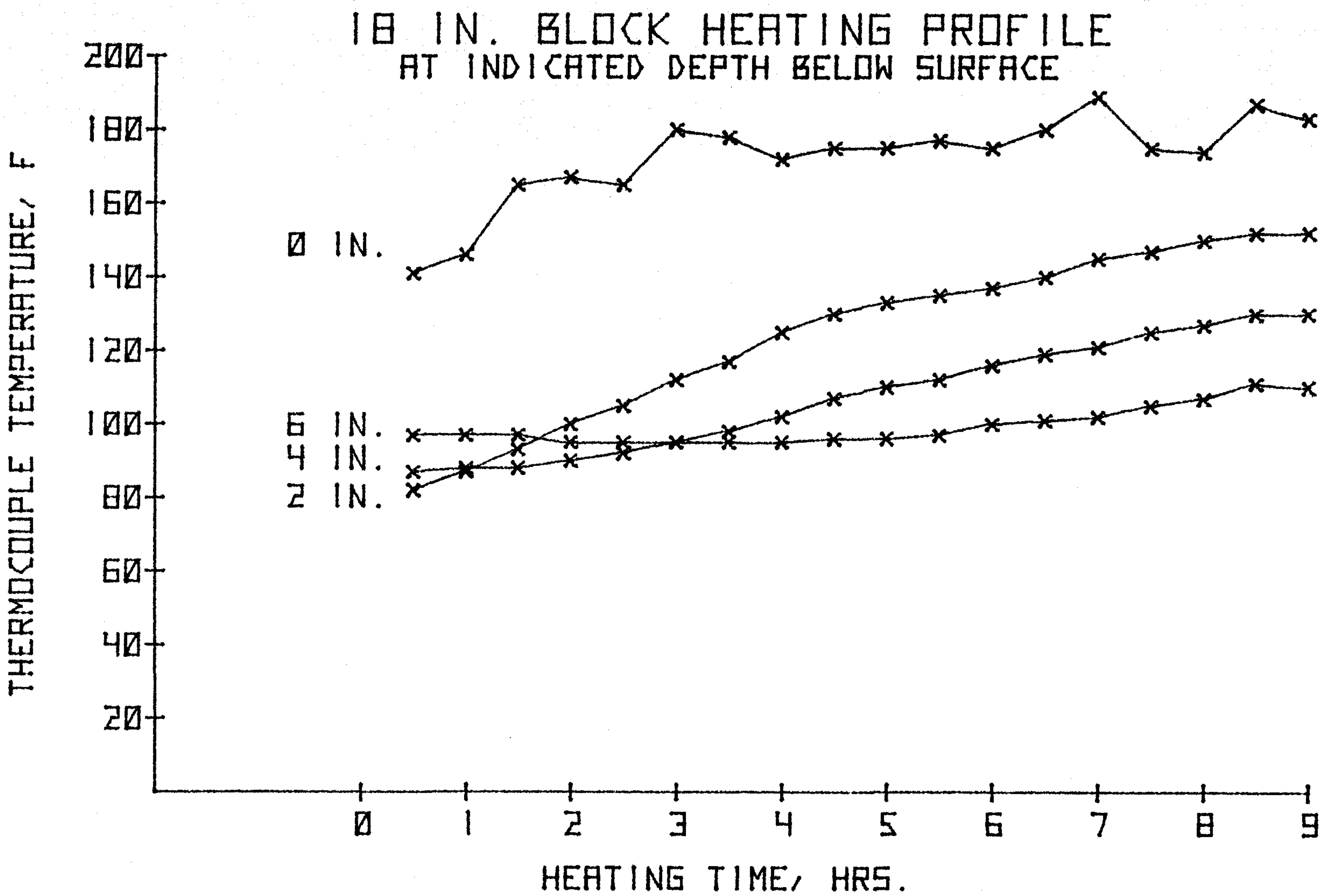


Figure 10. Eighteen Inch Diameter Block Heating Profile from Treatment (Vat) 1.

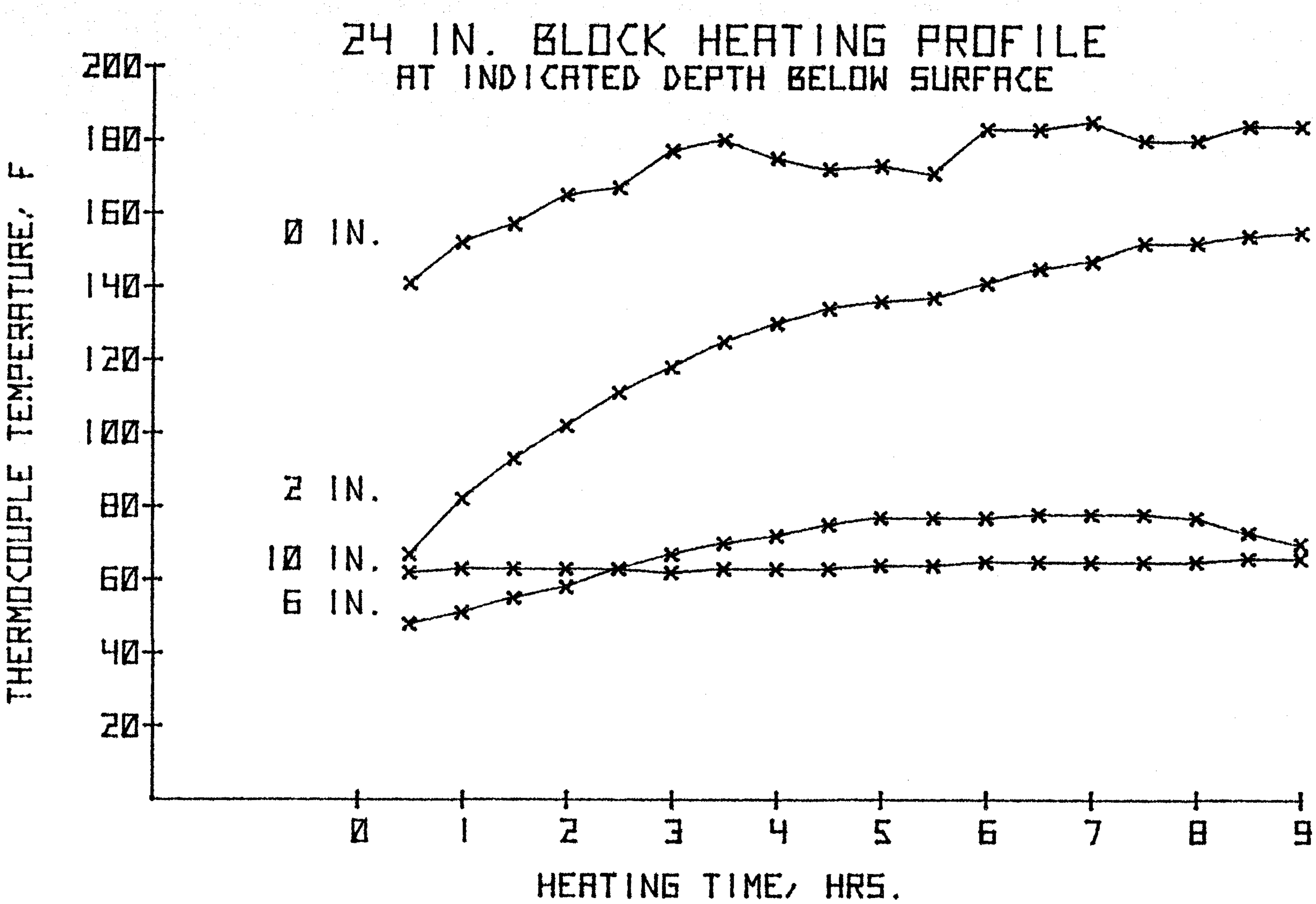


Figure 11. Twenty-four Inch Diameter Block Heating Profile from Treatment (Vat) 1.

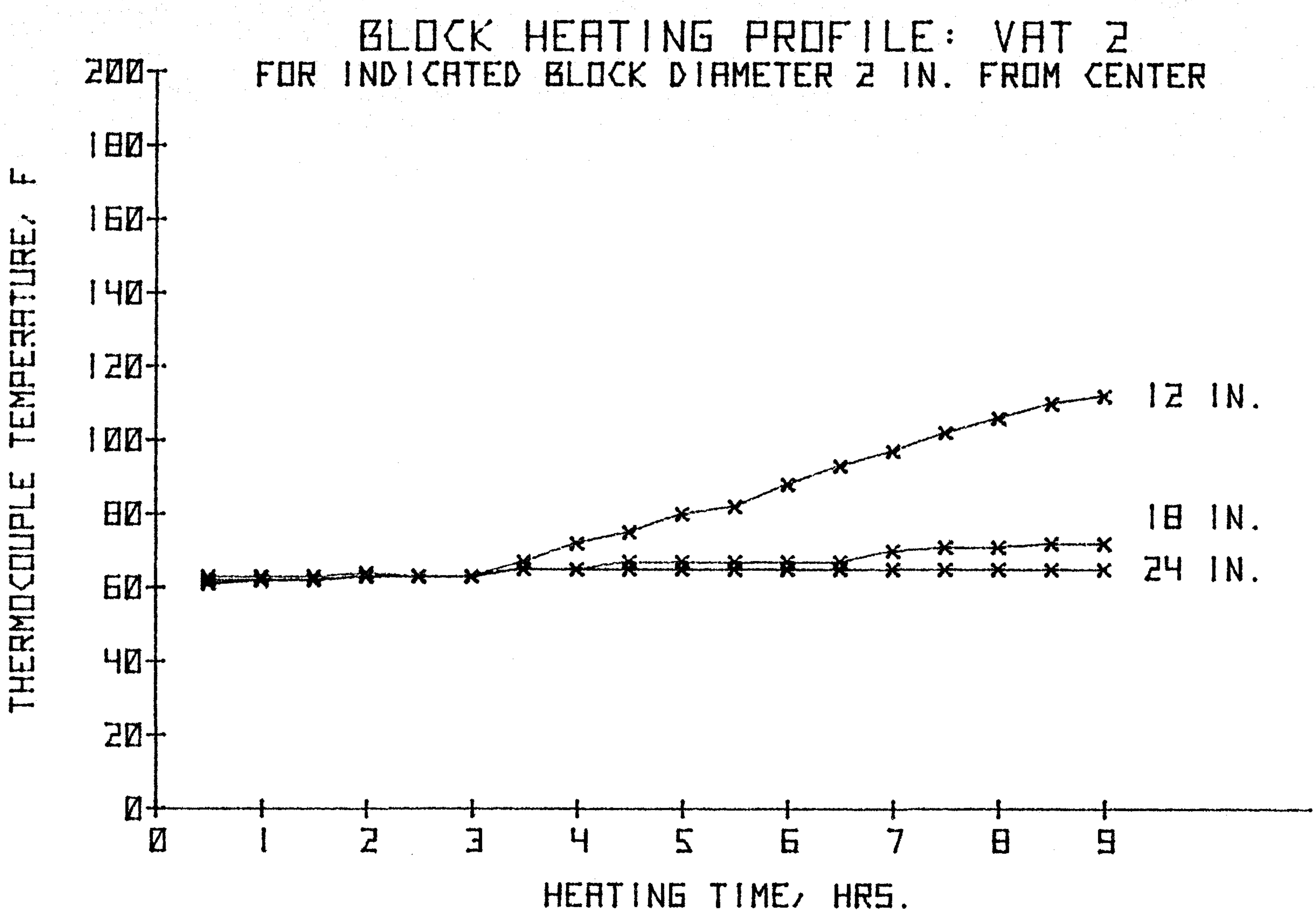


Figure 12. Block Heating Profiles from Treatment (Vat) 2: 12, 18, and 24 Inch Diameter Blocks.

less than 3/8 inch in diameter, were drilled in the blocks. The wire was inserted to the bottom of the hole and the hole was plugged with quick setting thermoplastic resin, as suggested by Bramhall (1974).

A total of 15 points were sampled once every 12 seconds (each point was recorded once every three minutes). The chart speed was 16 inches per hour.

Vat Comparisons. The heating profiles obtained from the two vats indicate that approximately the same temperature (within the thermocouple wire measurement accuracy of $\pm 4^{\circ}$F) two inches from the center was reached for the 24 inch diameter blocks. The temperatures recorded for the 12 inch diameter blocks at the same depth showed that the vat 2 block was 16 percent lower in temperature than the vat 1 block (112°F versus 130°F, respectively). There was some 40°F temperature difference in the 18 inch diameter block between vats.

The poor agreement in temperature at a similar depth and time for the 18 inch blocks could have been due to heat transfer along the thermocouple within vat 1. A poor seal around the wire would have caused a higher temperature at the tip of the thermocouple wire. A comparison of the temperature readings of the 18 inch block with both the 12 and 24 inch blocks for a similar depth and time shows the 18 inch block temperature to be 40°F higher, about the same discrepancy indicated between vats for the 18 inch logs. In summary, it seems reasonable to conclude that the temperature indicated for the 18 inch block in vat 1 exhibited measurement error.

The initial, final, and rate of temperature increase for the 12 and 24 inch blocks seemed to be in the range expected. No explanation could be found for the vat difference in temperature of the 12 inch blocks. At the end of heating, the indicated temperatures for the 12 inch block at the core (2 inches from the center) were approximately 135°F and 120°F for vat 1 and vat 2, respectively.

Diameter and Within Block Comparison. Between block diameters, as distance from the block surface increased, the temperature attained after a given heating time decreased. This is illustrated particularly well when comparing the measured temperatures for each block in vat 2 (Figure 12). Within a given block, as distance from the surface increased, the time required to reach a desired temperature increased. Both the between diameter and within diameter temperature differences with time are the result of the amount of wood material that the heat must flow through. A greater distance from the heating medium existed and since the heat flow diagrammed is unsteady state in nature, as the temperature gradient between two points decreases the rate of temperature change decreases.

The insulative nature of wood could be exhibited in Figure 11. The initial thermocouple reading for the 24 inch block at the ten inch mark is some 10°F higher than the six inch mark. As heating progressed, the six inch point reached a higher temperature than the 10 inch point but neither point approached the desired block temperature after nine hours.

The temperature profiles of the blocks during heating, as indicated by the thermocouples, did exhibit a heating pattern as predicted by the theoretical calculations determined by the block heating program.

Actual Block Temperature and Theoretically Derived Temperature

For the sake of completeness, the actual temperatures as sensed by the thermocouple readings after three, six and nine hours of heating are presented in Table 7 along with theoretical temperatures as calculated from MacLean (1952). For the theoretical calculations, it was assumed that the initial temperature was 50^{o}F, heating medium temperature was 180^{o}F, and steam was the heating medium. A thermal diffusivity of 0.0003 square inch per second was assumed for green Douglas-fir.

Valid statistical comparisons cannot be made between the actual temperatures as indicated by the thermocouple and the theoretical temperatures as derived by MacLean. The actual temperature values presented in Table 7 represent a single observation. Consequently, there are no degrees of freedom on which to base a reliable statistical measure of actual block temperatures.

Lathe Temperature Profiles

Plots of the average of two consecutive temperature measurements as recorded by the data acquisition system are given in Figures 13, 14, and 15. The temperature sensing instrument (Nova) and the data acquisition system appeared to repeatably measure the veneer temperature in a range that agrees with the thermocouple measured final block temperatures. The temperatures recorded two inches from the center of the 12 inch block during heating were 130^{o}F from vat 1 and 112^{o}F from vat 2. The temperatures measured by the Nova at peel times that corresponded to near core kickout were 125^{o}F for vat 1 and 110^{o}F for vat 2. The temperature profiles measured at the lathe compare favorably with the thermocouple readings for the 18 and 24 inch blocks also. As indicated

Table 7. Actual Block Temperatures versus Theoretical Temperatures as Calculated from MacLean (1952) of a Point Two Inches From the Center as a Round Block.

		Actual	MacLean
12 In. Block Diameter			
Distance from Surface: 2 in.			
Elapsed heating time:			
	3 hrs.	110°F	123°F
	6	137	147
	9	151	163
Distance from Surface: 4 in.			
Elapsed heating time:			
	3 hrs.	79°F	82°F
	6	105	123
	9	126	150
18 in. Block Diameter			
Distance From Surface: 2 in.			
Elapsed heating time:			
	3 hrs.	120°F	117°F
	6	136	138
	9	151	150
Distance From Surface: 4 in.			
Elapsed heating time			
	3 hrs.	94°F	73°F
	6	114	102
	9	126	116
Distance From Surface: 6 in.			
Elapsed heating time			
	3 hrs.	94°F	56°F
	6	96	76
	9	105	99

Table 7. Actual Block Temperatures versus Theoretical Temperatures as Calculated from MacLean (1952) of a Point Two Inches From the Center as a Round Block.

		Actual	MacLean
24 in. Block Diameter			
Distance From Surface: 2 in.			
Elapsed heating time			
	3 hrs.	117°F	117°F
	6	136	135
	9	156	146
Distance From Surface: 6 in.			
Elapsed heating time			
	3 hrs.	66°F	56°F
	6	77	71
	9	87	88
Distance from Surface: 10 in.			
Elapsed heating time			
	3 hrs.	66°F	51°F
	6	63	53
	9	63	62

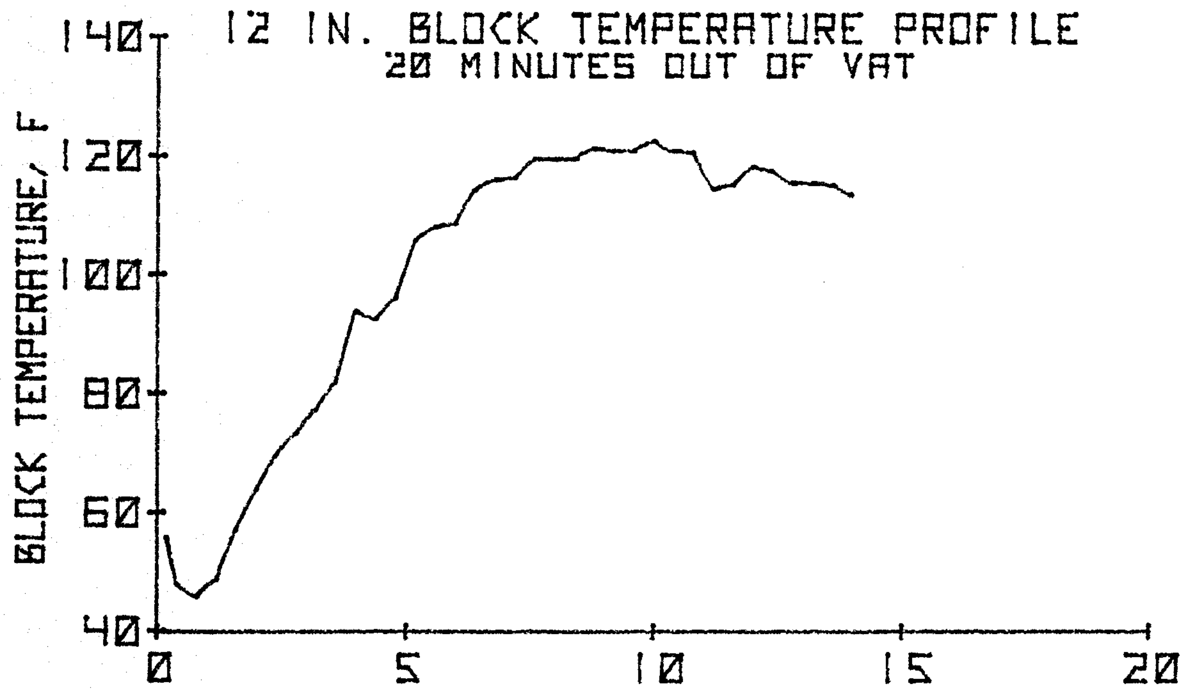
Initial Temperature: 50°F
Heating Medium Temperature: 180°F
Heating Medium: Steam

earlier, the lathe-knife position readings were not reliable. Therefore, Figures 13, 14, and 15 present temperature versus elapsed peel time.

Greater than expected temperature variation along the block radius is exhibited in the profiles. The general shape of the profiles can be explained physically.

Block Temperature Distribution at the Lathe. Immediately after removal from the heating medium, the highest block temperature, T_H, is at the block surface. This point begins to lose heat via conduction to the cooler block interior, and convection to the surrounding air. At some time after removal from the heating medium, the position along the radius r of the highest temperature T_H is a function of the time since removal from the heat, the surrounding air temperature T effecting cooling via convection,and the parameters effecting heat conduction in the wood from the highest temperature T_H to the interior temperature T_C and the surface temperature T_S.

The location of T_H along the radius r occurs in the first half of the total peel time for each block in the figures. T_H is obviously not too far from the surface since it takes longer to reduce the radius at the beginning of peel than near the end of peel. The veneer peeled from near the surface was at near ambient temperature T . As peeling progressed the temperature increased to T_H along the radius. For the 12 inch blocks, which heated nearly throughout the block (Figure 13) after nine hours, the temperature at the core T_C is not much less than the highest block temperature T_H. The 18 and 24 inch blocks did not heat as uniformly (Figures 14 and 15), so the core temperature T_C is much lower



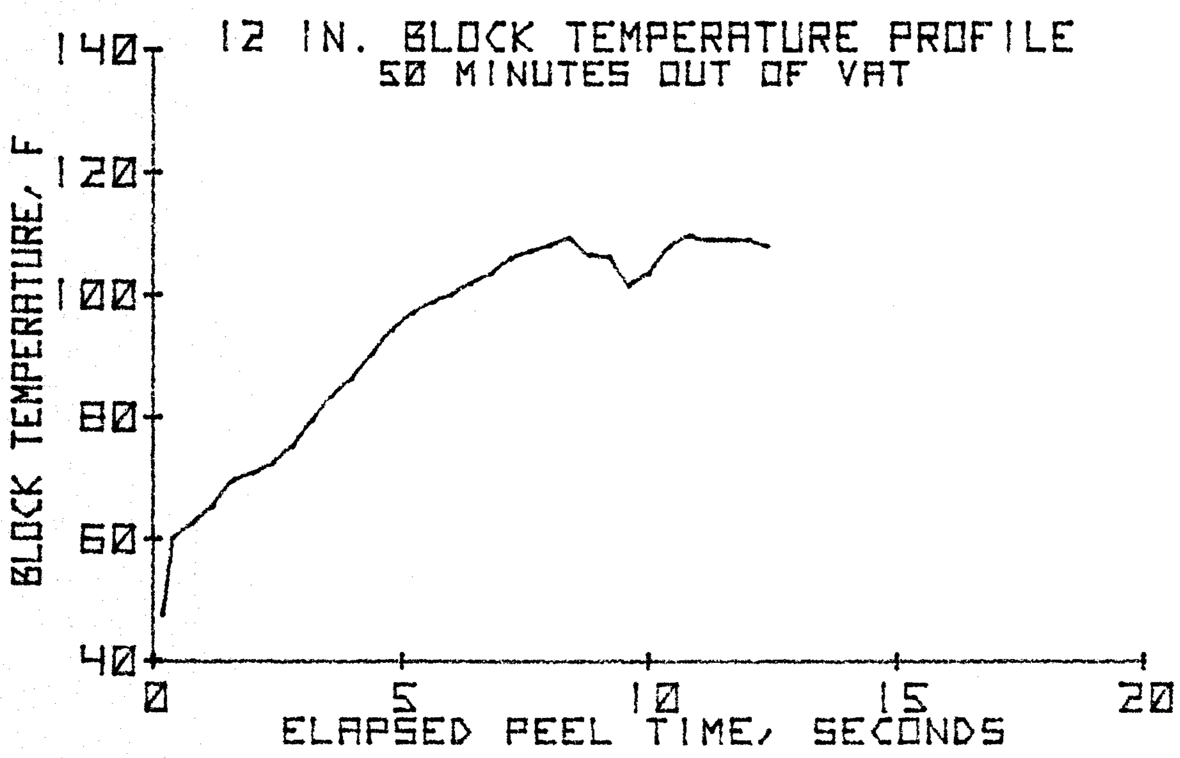
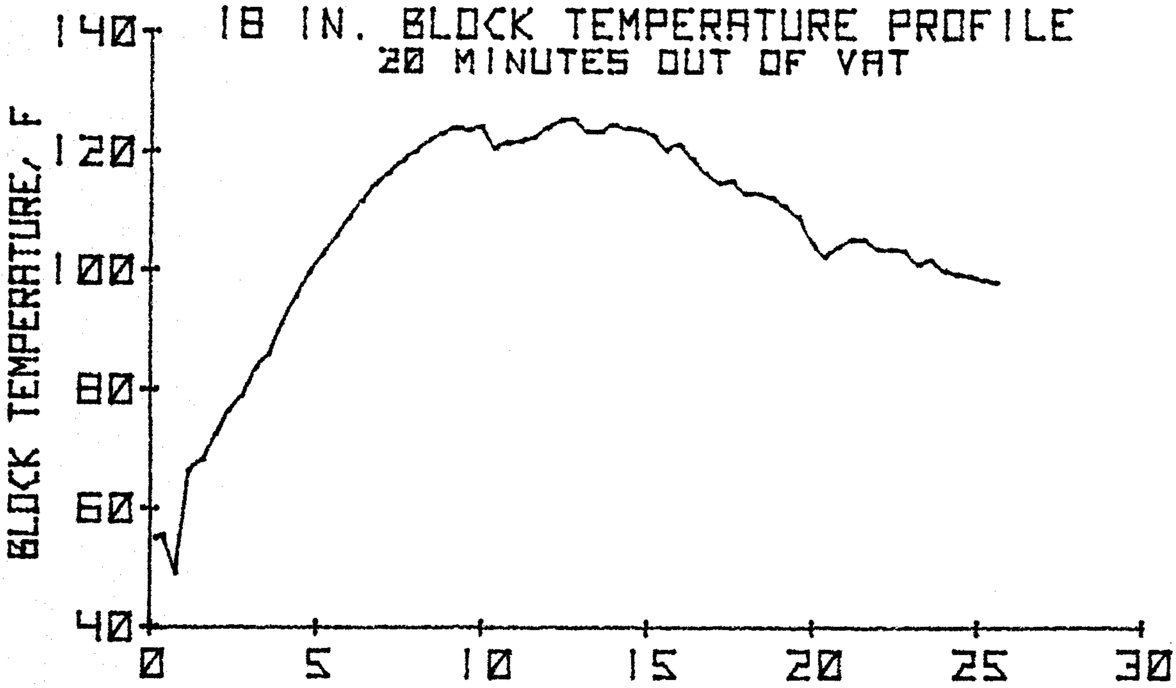


Figure 13. Twelve Inch Diameter Block Temperature Profiles as Recorded at the Lathe.



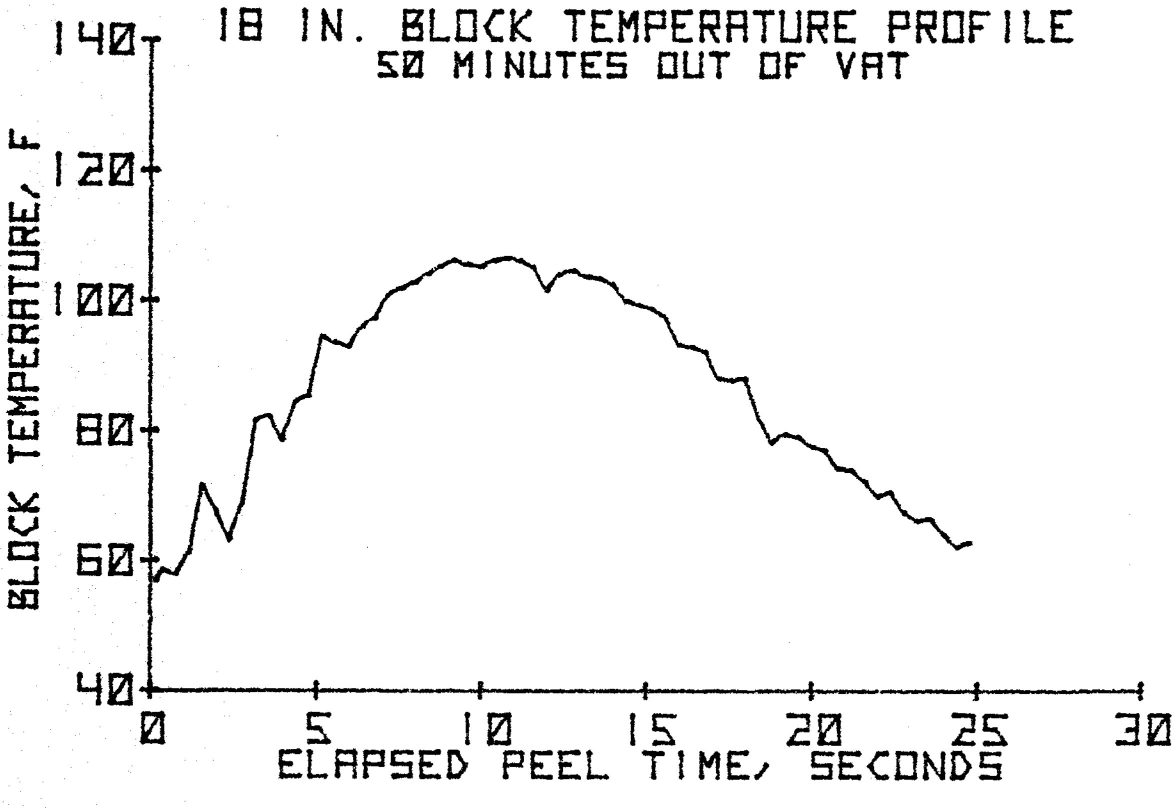
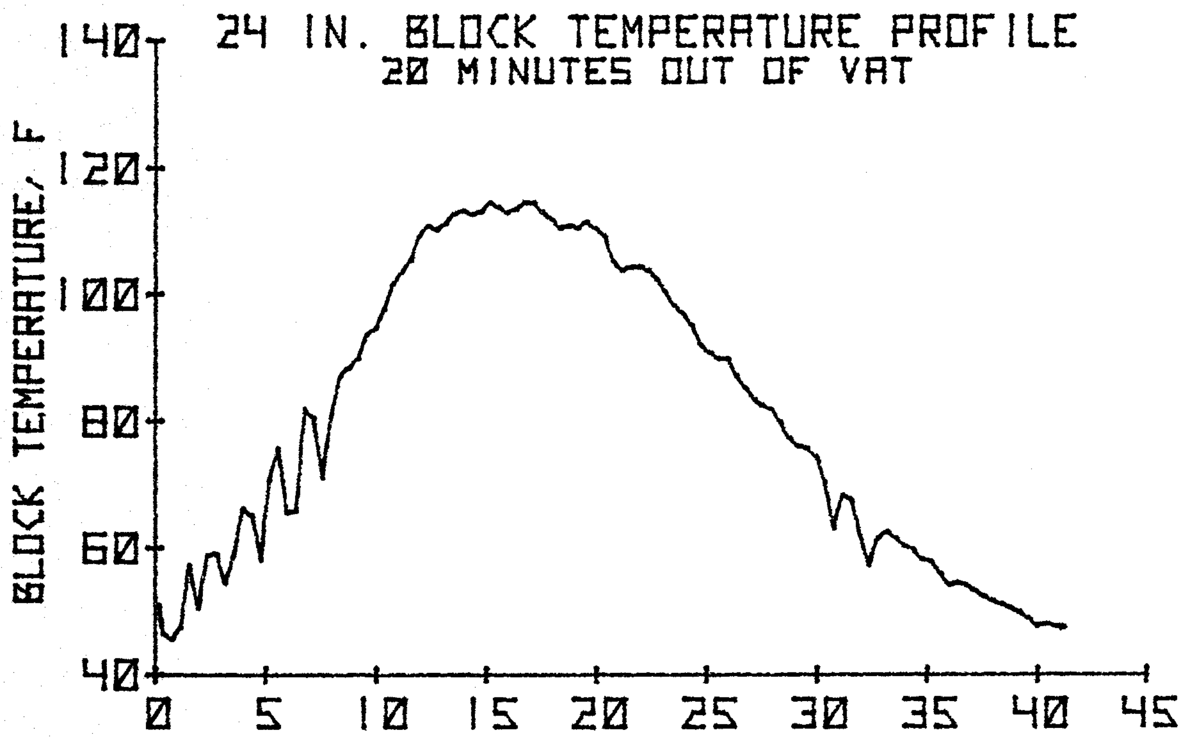


Figure 14. Eighteen Inch Diameter Block Temperature Profiles as Recorded at the Lathe.



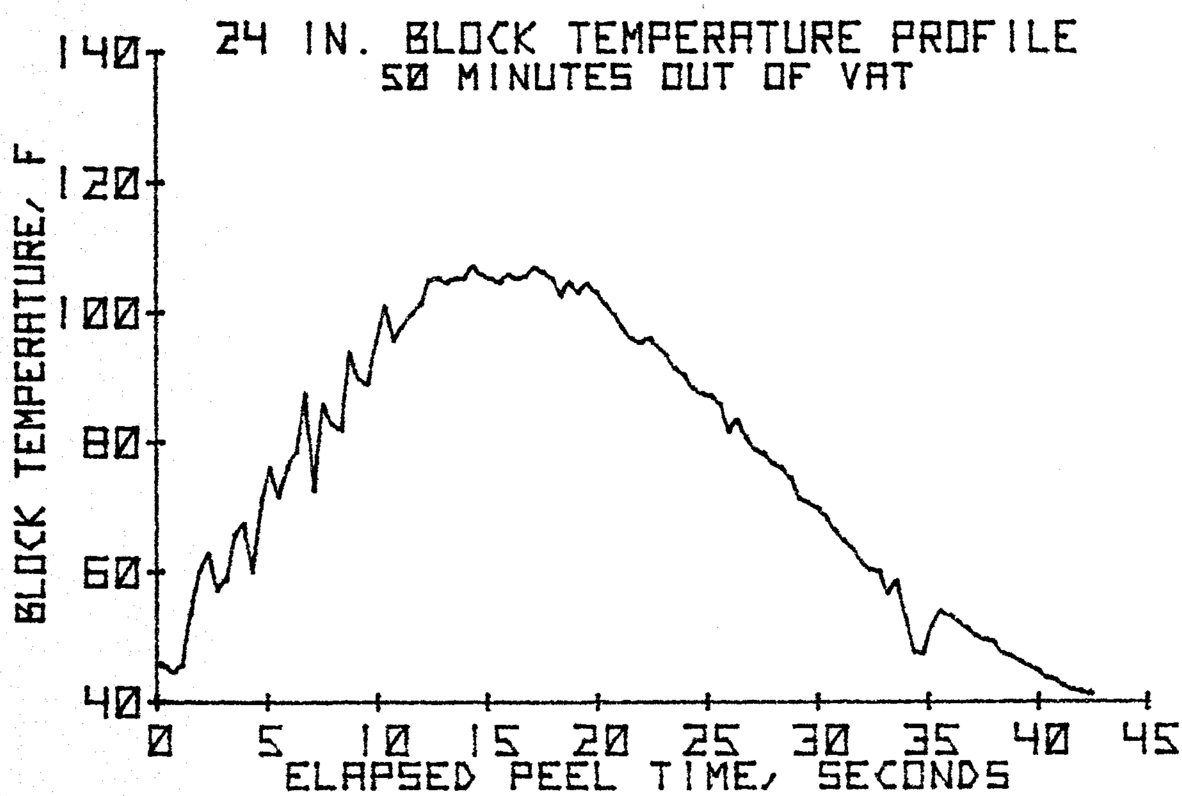


Figure 15. Twenty-four Inch Diameter Block Temperature Profiles as Recorded at the Lathe.

than the highest temperature T_H. The cooling of the logs is a function of the log diameter, as was the heating.

In each figure, the highest temperature T_H and the core temperature T_C is lower for the blocks exposed 50 minutes. Whether the lower temperature is completely due to the longer exposure time is not clear. For each of the 12 and 18 inch block diameters, the thermocouple readings after nine hours indicated a lower core temperature T_C for vat 2 (exposed 50 minutes) than vat 1 (exposed 20 minutes).

In summary, the block temperature profiles as recorded at the lathe appear to be an accurate reflection of actual veneer temperature. The temperature is a function of both time of exposure to the surrounding medium and block diameter. The non-uniformity of temperature within a block leads one to believe the effects of heating on veneer production would vary greatly for any one block.

Summary

The discussion presented to assess the validity of the temperature profiles recorded is by no means complete. Time series analysis, mass transfer, and measurement theory would have to be utilized to fully explain the temperature distributions. This was not the intent of this project. Rather, a means of continuously monitoring block temperature to control the heating process was the desired result.

The modifications on the data acquisition system necessary for improved block temperature sensing would be a reliable lathe-knife position sensor to indicate the relative location of the temperature variations along the block radius, and program revision to better utilize computer memory. Block temperatures could then be monitored and heating practices modified if precisely controlled block temperatures at the time of peeling was necessary.

Veneer Yield Recovery Results

Once again, for the discussion treatment 1 will be referred to as the "hot" blocks (20 minutes out of vat before peeling); treatment 2 will be known as "warm" (50 minutes out of the vat before peeling). Treatment 3 (peeled unheated) will be referenced as the "cold" blocks. Ambient temperature was 40 to 45°F on each day.

Preliminary Analysis

The veneer recovery by day, treatment, and diameter for each veneer grade and item on a volume 3/8 inch basis are given in Tables 8 through 10. Table 11 presents veneer recovery, on a volume 3/8 inch basis for each block diameter by treatment, veneer sheet length, and grade. Table 12 gives veneer recovery and cubic volumes by treatment and diameter. Core volumes are not given because the cores were processed by mill personnel before the cores' cubic volumes could be measured.

The percentage of veneer recovered by grade and veneer item for all 81 blocks is shown in Table 13, and it shows that very little veneer was recovered in some combinations of veneer grade and item. Most blocks yielded no A, AB, or B grade veneer. The large percentage of the blocks sampled with zero recovery in some grades causes an underlying assumption of analysis of variance to be violated. To achieve the desired operating characteristics of an analysis of variance, experimental errors must have a common variance. Clearly, if there were no

Table 8. Volume Recovery by Grade, Item and Day; 3/8 Inch Basis; Square Feet.

Veneer Item	Veneer Grade A	AB	B	C	CD	U	Total	Reject
Day 1, 27 Blocks								
Full	281	0	0	3345	15	957	4598	30
Half	123	0	0	247	1282	235	1887	5
Random	181	0	0	329	737	98	1346	0
Fishtail	98	0	0	291	5	58	452	0
Total	683	0	0	4212	2039	1348	8283	35
Day 2, 27 Blocks								
Full	0	0	0	1105	2587	0	3692	0
Half	172	0	0	867	1563	537	3140	0
Random	0	0	0	83	1680	51	1815	0
Fishtail	22	0	0	123	154	47	345	0
Total	194	0	0	2178	5984	634	8992	0
Day 3, 27 Blocks								
Full	0	121	0	2916	2474	0	5511	0
Half	157	0	119	1380	716	215	2585	0
Random	8	0	0	11	1449	109	1578	0
Fishtail	0	0	0	0	285	0	285	0
Total	165	121	119	4307	4924	323	9959	0

Table 9. Volume Recovery by Grade, Item and Treatment: 3/8 Inch Basis; Square Feet.

Veneer Item	Veneer Grade							
	A	AB	B	C	CD	U	Total	Reject
Treatment 1 (Hot), Blocks								
Full	70	0	0	2446	1749	844	5109	0
Half	25	0	0	1026	1062	698	2811	0
Random	59	0	0	108	1546	107	1820	0
Fishtail	41	0	0	90	206	43	380	0
Total	195	0	0	3670	4563	1692	10120	0
Treatment 2 (Warm), 27 Blocks								
Full	211	121	0	2953	1497	73	4855	10
Half	167	0	5	464	860	116	1562	0
Random	75	0	0	136	1130	50	1391	0
Fishtail	38	0	0	160	150	35	383	0
Total	441	121	5	3713	3637	274	8191	10
Treatment 3 (Cold), 27 Blocks								
Full	0	0	0	1967	1831	40	3837	20
Half	310	0	113	1006	1639	172	3239	5
Random	55	0	0	180	1191	101	1527	0
Fishtail	41	0	0	163	88	27	319	0
Total	406	0	113	3316	4748	340	8922	25

Table 10. Volume Recovery by Grade, Item and Diameter: 3/8 Inch Basis; Square Feet.

Veneer Item	Veneer Grade						Total	Reject
	A	AB	B	C	CD	U		
12 Inch, 27 Blocks								
Full	0	0	0	1638	151	30	1819	0
Half	0	0	0	360	414	123	896	0
Random	0	0	0	44	866	49	960	0
Fishtail	0	0	0	104	71	14	188	0
Total	0	0	0	2146	1502	214	3863	0
18 Inch, 27 Blocks								
Full	281	60	0	3238	2071	100	5751	10
Half	192	0	25	883	1202	152	2454	0
Random	140	0	0	137	1303	67	1648	0
Fishtail	69	0	0	88	189	28	375	0
Total	682	60	25	4346	4765	347	10228	10
24 Inch, 27 Blocks								
Full	0	61	0	2489	2854	828	6232	21
Half	259	0	94	1253	1946	711	4263	5
Random	49	0	0	242	1698	142	2131	0
Fishtail	51	0	0	221	183	63	518	0
Total	359	61	94	4205	6681	1744	13144	26

Table 11. Veneer Recovery by Item, Grade Treatment for 12 inch Blocks: 3/8 inch basis; square feet.

12" Diameter Blocks			
	Treatment		
	Hot	Warm	Cold
Full Sheets			
AB	0	0	0
CD	553	562	673
U	20	0	10
Total	573	562	683
Half Sheets			
AB	0	0	0
CD	232	266	276
U	29	69	24
Total	271	335	300
Random Width			
CD	455	266	230
U	11	19	17
Total	466	285	247
Fishtails			
CD	109	28	52
Total	1419	1210	1282

Table 11. Veneer Recovery by Item, Grade Treatment for 18 inch Blocks: 3/8 inch basis; square feet.

	18 " Diameter Blocks		
	Treatment		
	Hot	Warm	Cold
Full Sheets			
AB	70	271	0
CD	1949	1609	1752
U	30	50	20
Total	2049	1930	1772
Half Sheets			
AB	0	10	183
CD	722	624	988
U	108	18	30
Total	830	652	1201
Random Width			
CD	556	573	450
CU	31	15	22
Total	587	588	472
Fishtails			
CD	108	127	99
Total	3574	3297	3544

Table 11. Veneer Recovery by Item, Grade Treatment for 24 inch Blocks: 3/8 inch basis; square feet.

24 " Diameter Blocker

	Treatment		
	Hot	Warm	Cold
Full Sheets			
AB	0	61	0
CD	1693	2278	1374
UD	794	23	10
Total	2487	2362	1384
Half Sheets			
AB	25	107	127
CD	1134	665	1495
U	560	33	118
Total	1719	805	1740
Random Widths			
CD	701	541	746
U	64	16	62
Total	765	557	808
Fishtails			
CD	142	198	145
Total	5113	3922	4077

Table 12. Veneer Recovery and Cubic Volumes by Treatment and Diameter, 3/8 Inch Basis.

Diameter, inches		Number of Blocks	Volume, 3/8" basis, sq. ft.	Volume: Block, cu. ft.	Volume: Veneer, cu. ft.	Percent
12	Hot	9	1409	65.01	44.03	68.2
	Warm	9	1170	60.26	40.08	58.9
	Cold	9	1282	62.16	40.08	64.6
18	Warm	9	3597	147.06	112.42	76.8
	Warm	9	3084	152.28	96.38	64.4
	Cold	9	3545	144.56	110.79	76.6
24	Hot	9	5114	241.90	159.82	66.7
	Warm	9	3936	227.27	123.01	53.4
	Cold	9	4094	233.38	127.95	55.0
Total or Average	81	27234	1339.00	851.08	65.0	

Table 13. Percentage of Veneer Recovery by Grade and Item.

Veneer Grade	Number of Blocks	Volume Recovered 3/8" Basis sq. ft.	% Veneer of Block Volume	% of Veneer Recovered	% Full Sheets Recovered	% Half Sheets Recovered	% Random Widths Recovered	% Fishtail Recovered
A	81	1042	2.02	3.83	1.03	1.66	0.70	0.44
AB	81	121	0.23	0.44	0.44	0	0	0
B	81	118	0.20	0.43	0	0.43	0	0
C	81	10798	28.46	39.28	27.05	9.16	1.56	1.52
CD	81	12949	29.57	47.55	18.64	13.08	14.20	1.63
Utility	81	2305	4.47	8.46	3.51	3.62	0.95	0.38
Total or Average	81	27233	64.95	100.00	50.67	27.94	17.40	3.97
Reject	81	36	0.01	-	0.11	0.02	0	0

measurement of recovery, the experimental error associated with that lack of measure for some blocks will be less than the errors in other blocks that did yield some A, AB, and B grades. The heterogeneity of error variance might show significant differences between means where they do not exist (Duncan, 1974). Since the error variance associated with grades A, AB, and B may be heterogenous, a greater probability exists that the analysis of variance would detect differences falsely. It must be concluded that the analysis of variance for grades A, AB, and B is not valid.

For the sake of completeness, all ANOVA tables are included in Appendix A. However, veneer yield by grade and veneer item will not be discussed based on F-statistic for grades A, AB, and B.

Examination of the veneer recovery as recorded on each day (Table 8) shows the grading inconsistencies previously noted. Full and half sheets were not always separated into grades A, AB, and B or C and CD regularly from day to day. Random widths and fishtail items exhibited similar tendencies. Therefore, for purposes of analysis, grades C and CD were combined into grade CD for all veneer items.

Grade, Item and Volume Recovery

Grade CD Recovery. Observation of the analysis of variance (Appendix Tables A1-1) for grade DC shows a highly significant (.99 level) diameter effect on the recovery of full sheets as well as a significant (.95 level) diameter * treatment interaction. The diameter * treatment interaction is shown in Table 14, and it shows no discernable pattern of interaction (the greatest and the least

Table 14. Percentager of Block Volume Recovered as Full Sheets of Grade CD.

Treatment	Diameter, inches		
	12	18	24
Hot	26.8	41.8	22.2
Warm	27.8	34.1	31.5
Cold	33.4	38.3	17.7
Average	29.4	38.1	23.8

percentage recovery for each treatment are for a different diameter class). The F-value of 3.31 is marginally significant $[F^2_4(0.05) = 3.26]$ and together with the lack of a logical pattern of interaction, no firm conclusion about the cause of the interaction can be made.

Diameter alone shows the 18 inch blocks had the greatest full sheet recovery followed by the 12 inch blocks and then the 24 inch blocks with the least recovery. A reason for a maximum of 18 inches is not clear. Other veneer recovery work showed a similar trend. Data on volume recovery for Douglas-fir No. 3 Sawmill logs from Fahey (1974) in Table 15 shows a maximum recovery percentage at 18 inches. The percentage recovery for the 12 and 24 inch blocks is practically identical, however.

The effect of wood defects (knots, rot, pitch, etc.) has already been accounted for since the full sheet recovery differences are significant within the grade CD. Therefore, the differences in full sheet recovery at the various diameters most probably can be assigned to a block diameter-lathe geometry interaction arising from the machining process or a difference in growth characteristics between the logs. Lutz (1978) said an ideal peeler log should be of uniform slow growth (no measurement of growth rate was made for this study). Empirical studies (Knudson et al., 1975) have shown that lathe settings alone can provide substantial increases in yield of wide veneer of over ten percent. Further study is necessary to identify the cause of the block diameter-full sheet yield interaction.

Observation of the analysis of variance (Appendix Tables A-1) for CD also shows a significant (.95 level) effect of treatment on the

Table 15. Percentage Veneer Recovery by Block Volume and Diameter for Douglas-fir No. 3 Sawmill Blocks, 1/10-inch Veneer (Fahey, 1974).

Block Diameter Range (in.)	11-13	17-19	23-24
Number of Blocks Peeled	21	3	4
Percentage Recovery (%)	38.1	44.2	38.3

recovery of half sheets. Half sheets of grade CD (Table 16) had a substantial recovery of 23 percent of all veneer recovered (6055 square feet, 3/8 inch basis). Data in Table 17 show that the unheated blocks yielded more half sheets than either the hot or cold treatment. There was, as expected, a corresponding decrease for full sheets due to the increased half sheets. The range of full sheet versus half sheet change across the treatements (1.4 percent and 8.6 percent, respectively) indicates the increased half sheet recovery did not come at the expense of full sheet recovery. An explanation for the significant treatment effect on half sheets is not obvious, but it did not come at the expense of full sheets.

Utility Grade Recovery. Observation of the analysis of variance for Utility grade (Appendix Tables A-1) by veneer item shows no significant difference for any source of variation. However, the analysis of variance for volume recovery regardless of veneer item (Appendix Tables A-2) shows a significant (.95 level) diameter * treatement interaction as well as a significant effect of diameter. The interaction will contain the more meaningful information. Data in Table 18 shows that 24 inch blocks peeled hot yielded substantially more veneer. The effect of block temperature at the lathe on the recovery is questioned, however, since the temperature profiles recorded at the lathe showed that only a small percentage of the block was at temperatures thought to be necessary to attain benefits from preheating. Table 8 shows that the only full sheet Utility grade veneer was recovered on the first day of the study. This suggests that the treatment * diameter interaction can be assigned to degrade to Utility as a result of defects in the 24 inch

Table 16. Veneer Recovery by Green Veneer Grade.

Veneer Grade	Number of Blocks	Volume Recovered 3/8" Basis sq. ft.	% Veneer of Block Volume	% of Veneer Recovered	% Full Sheets Recovered	% Half Sheets Recovered	% Random Widths Recovered	% Fishtail Recovered
A	81	1163	2.45	4.27	1.47	1.66	0.70	0.44
CD	81	23765	58.03	87.27	45.69	22.57	15.76	3.15
Utility	81	2305	4.47	8.46	3.51	3.62	0.95	0.38
Total or Average	81	27233	64.95	100.00	50.67	27.94	17.40	3.97

Table 17. Percentage of Block Volume Recovered as Full and Half Sheets of Grade CD.

Treatment	Full Sheets	Half Sheets
Hot	30.3	14.0
Warm	31.2	10.1
Cold	29.8	18.6

Table 18. Percentage of Block Veneer Recovered as Utility Grade Veneer.

Treatment	Diameter, inches 12	18	24
Hot	3.5	3.3	18.7
Warm	4.4	2.1	1.9
Cold	2.9	1.6	2.9

blocks peeled on the first day.

Appendix Tables A-2 also shows a significant (.95 level) effect of diameter on recovery of grade C. However, the inconsistent grade separation into grades C and CD prevents meaningful analysis.

Veneer Item Recovery. Observation of the analysis of variance for veneer item (Appendix Tables A-3) shows that diameter had a significant (.95 level) effect on the recovery of full sheets. Table 19 shows the percent of block volume recovered as full sheets for each diameter. This is the same trend as shown in full sheet recovery of grade CD and is expected since full sheets of CD accounted for 46 percent of the veneer recovered (Figure 16). Again, the recovery was independent of block treatment but a function of block diameter.

Total Veneer Recovery. Observation of the analysis of variance for total veneer recovery (Appendix Tables A-3) for all grades and veneer items, once again shows a significant difference (.95 level) between diameters. As shown in Table 20, the recovery for the 18 inch blocks is the greatest.

The lack of effect of treatment on veneer grade, veneer item and total recovery was unexpected. The recovery results found by Grantham and Atherton (1959) reported increased grade and full sheet yield as the result of peel temperature was in the A grade. They found no benefit from preheating in the lower veneer grades. For the No. 2 Special Peeler logs, the unheated blocks actually yielded one percent more veneer.

In this study, 87 percent of the veneer recovered was in grade CD while only four percent was in grade AB (Table 16). Fahey (1974) found

Table 19. Percentage of Block Volume Recovered as Full Sheets.

Diameter, inches	Number of Blocks	Percentage
12	27	29.8
18	27	41.1
24	27	27.8

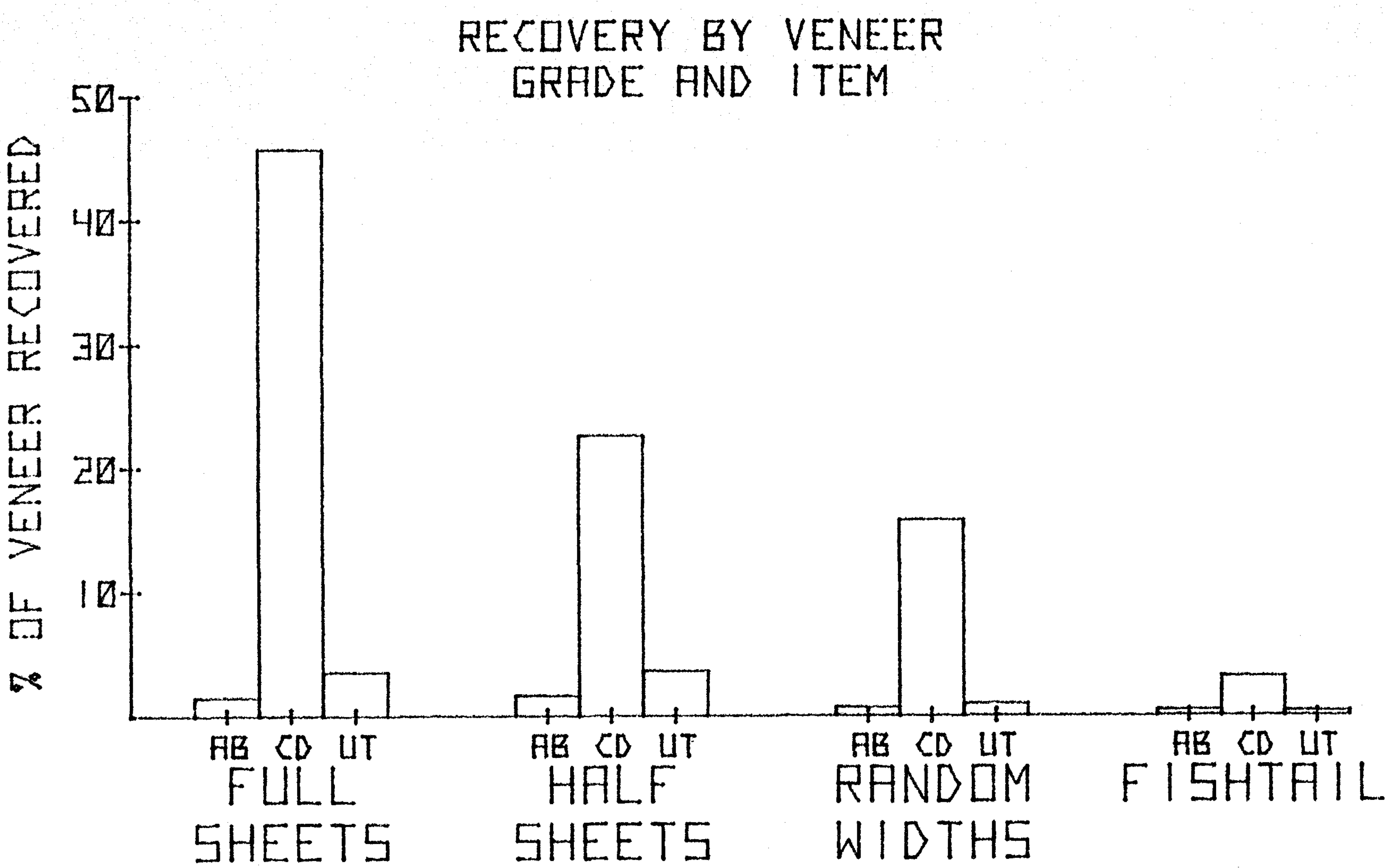


Figure 16. Veneer Recovery by Grade and Veneer Item.

Table 20. Percentage of Block Volume Recovered for Each Block Diameter.

Diameter, inches	Percentage
12	63.9
18	72.7
24	58.5

a similar lack of veneer in the upper grades (Figure 17). Only 3.1 and 1.2 percent recovery in grades A, AB, and B (APA PS1-74) were found for second growth Douglas-fir No. 2 and No. 3 Sawmill logs, respectively. The clear wood necessary to produce A-grade veneer does not exist in No. 2 and No. 3 Sawmill logs.

Examination of the treatment temperature profiles of the blocks could lead to some question as to whether adequate treatment temperature differences were achieved in the study blocks to obtain the proposed benefits of preheating. Treatment temperature profiles of the 24 inch blocks (Figures 11, 12, and 15) suggest that identifiable treatment temperature differences did not exist between the hot and warm 24 inch blocks. It could also be said that the heated (hot and warm) temperature treatments were not very different than the unheated or cold temperature treatment for the 24 inch blocks. No treatment differences may have existed for the 24 inch blocks to provide a basis for the expected gains of preheating. This same argument could be made for the 18 inch blocks as the treatment temperature profiles (Figures 10, 12, and 14) could lead to some question as to whether temperature treatment differences were achieved.

Observation of the treatment temperature profiles for the 12 inch blocks (Figures 9, 12, and 13), however, does not allow a similar argument to be made for the 12 inch diameter blocks. Clearly, treatment temperature differences did exist between the heated (hot and warm) temperature treatments and the unheated (cold) temperature treatment. If preheating treatment temperature were to have a significant effect on veneer recovery, the study design via the analysis of variance

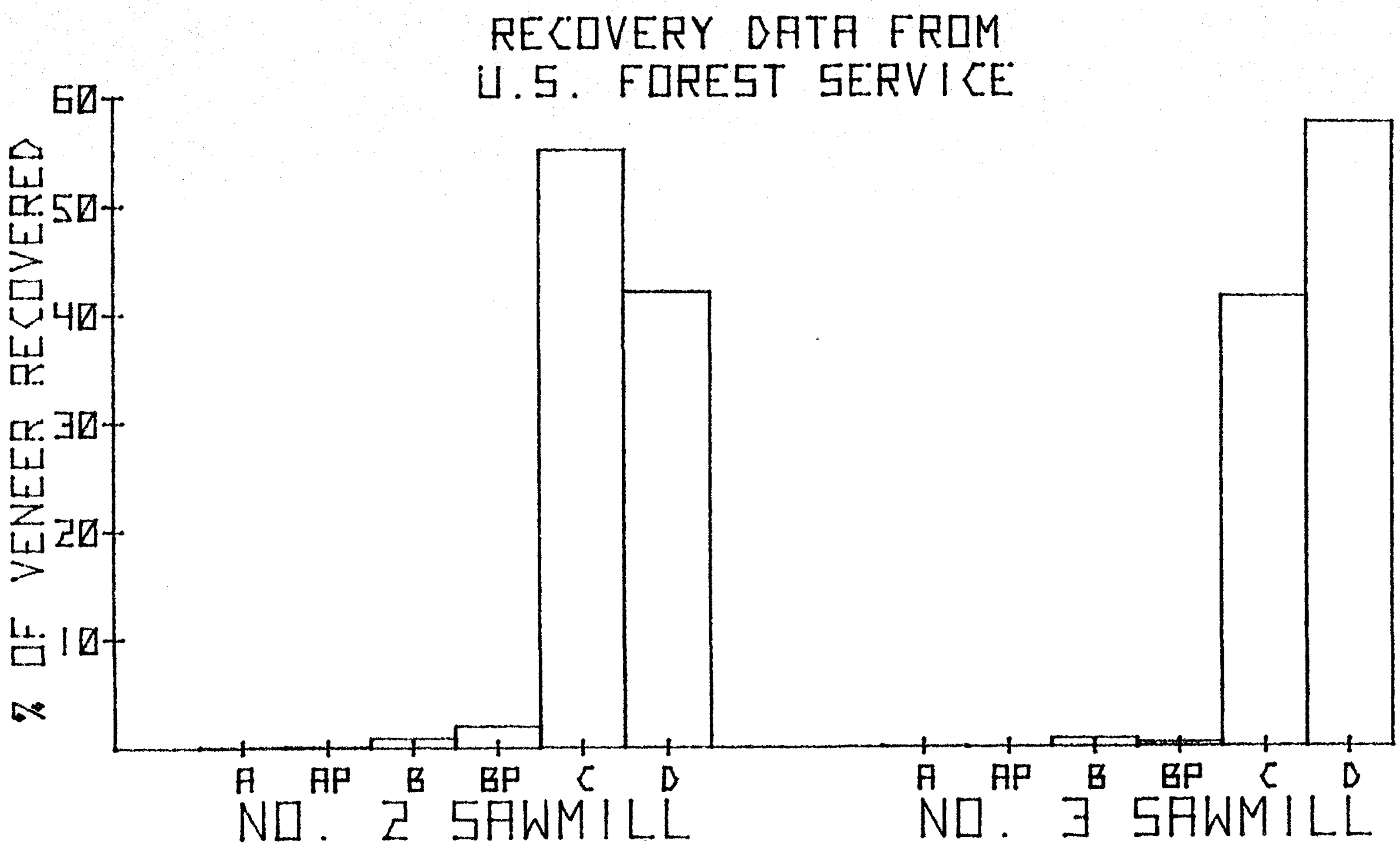


Figure 17. Veneer Recovery Data for Douglas-fir No. 2 and No. 3 Sawmill Logs (Fahey, 1974).

would have identified these differences based on the treatment temperature differences in the 12 inch blocks.

The results of this study indicate that the preheating treatment temperatures attained in this study did not sufficiently affect wood properties of Douglas-fir No. 3 Sawmill logs to upgrade veneer or to increase recovery of full sheet veneer.

Veneer Thickness

Observation of the analysis of variance for veneer thickness (Appendix Tables A-4) shows a significant effect (.95 level) of diameter on veneer thickness variation. The lack of influence of treatment on veneer thickness variation substantiates the results reported by Grantham and Atherton (1959) and Corder and Atherton (1963). In fact, as shown by Table 21, the treatment means were equal.

Analysis showed that a highly significant (.99 level) linear relationship existed between log diameters and veneer thickness variation. Again, a clear cause for this is not evident. Palka and Holmes (1973) studied the effect of log diameter and clearance angle of peel quality of 0.125-inch thick Douglas-fir veneer. The diameter range was five to 15 inches. They report veneer thickness decreased as block diameter increased from 11 to 15 inches. While their range of diameters or the thickness relationship with diameter does not agree with this study, the important conclusion is that there existed an effect of block diameter on thickness. The significant differences originating from block diameters on grade, full sheet, overall recovery and thickness indicate that the lathe-setting block diameter relationship needs much closer examination.

Table 21. Thickness Means, 0.001 Inch

Diameter, inches		
12	18	24
101.2	103.1	103.8

Treatment		
Hot	Warm	Cold
102.7	102.7	102.7

Overall Mean
102.7

Economic Feasibility

Veneer Value. Veneer value was computed in terms of dollars of veneer recovered per cubic foot of initial block volume. Table 22 presents the veneer value by treatment, sheet length, and grade for each block diameter. Table 23 provides a summary of Table 22. The value for the veneer grades and item was the average of the weekly price from January 1, 1978 to March 31, 1978 as reported by Random Lengths and Crow's newsletters.

No prices are reported by either publication for full sheets of Utility grade veneer, so industry sources were contacted. A value of $21 per 1000 square feet, fob mill, was established. Prices for all grades are given in Appendix Table B-1.

Observation of the analysis of variance for green veneer market value (Appendix Tables A-5) shows that diameter has a highly significant (.99 level) effect on total veneer and CD veneer value. Diameter also had a significant effect (.95 level) on AB and Utility grade green veneer value. Diameter * treatment interaction proved significant also. The relationship previously discussed concerning significant differences for each grade and veneer item are further reinforced. The 18 inch diameter blocks show the greatest value recovery, which was expected, since the 18 inch blocks yielded both the greatest percentage recovery and greatest percentage of full sheets. This combination of veneer grade and item increased the level of significance for the diameter effect from 0.95 to 0.99.

The analysis of variance was thought to be invalid for grades A,

Table 22. Green Veneer Market Values Per Cubic Foot of Block Volume for 12 Inch Diameter Blocks, Dollars.

12" Diameter Blocks

	Hot	Warm	Cold
Full Sheets			
AB	$ 0.00	$ 0.00	$ 0.00
CD	19.26	20.14	24.11
U	.42	0.00	0.00
Total	$19.68	$20.14	$24.32
Half Sheet	$ 0.00	$ 0.00	$ 0.00
CD	7.51	8.20	8.50
U	.54	.07	.45
Total	$ 8.05	$ 8.27	$ 8.95
Random Widths			
CD	$ 8.46	$ 4.93	$ 4.26
U	.16	0.02	.24
Total	$ 8.62	$ 4.95	$ 4.95
Fishtail			
CD	$ 1.55	$ 0.40	$ .24
Total	$37.90	$33.76	$38.01

Table 22. Green Veneer Market Values per cubicFoot of Block Volume for 18 Inch Diameter Blocks, dollars

	18" Diameter Blocks		
	Hot	Warm	Cold
Full Sheets			
AB	$ 4.08	$ 15.78	$ 0.00
CD	67.92	57.65	62.77
U	.63	1.05	.47
Total	$ 72.64	$ 74.48	$ 63.24
Half Sheets			
AB	$ 0.00	$ .56	$ 0.00
CD	22.24	19.23	10.29
U	2.01	.02	.56
Total	$ 24.25	$ 19.81	$ 10.85
Random Widths			
CD	$ 10.31	$ 10.62	$ 8.34
U	.44	.02	.31
Total	$ 10.75	$ 10.64	$ 8.65
Fishtails			
CD	$ 1.53	$ 1.80	$ 1.41
Total	$109.17	$ 106.73	$ 84.15

Table 22. Green Veneer Market Values per Cubic Foot of Block Volume for 24 Inch Diameter Blocks, dollars

	24" Blocks		
	Hot	Warm	Cold
Full Sheets			
AB	$ 1.41	$ 3.55	$ 0.00
CD	58.97	84.62	49.23
U	16.67	0.48	.21
Total	$ 77.05	$ 85.65	$ 49.44
Half Sheets			
AB	$ 0.00	$ 6.02	$ 7.14
CD	34.94	20.49	46.06
U	10.40	.03	2.19
Total	$ 50.34	$ 26.54	$ 55.39
Random Widths			
CD	$13.00	$10.03	$13.83
U	.91	.02	.88
Total	$ 13.91	$ 10.05	$ 14.61
Fishtail			
CD	$ 2.02	$ 2.81	$ 2.06
Total	$143.32	$125.05	$121.50

Table 23. A Summary of Green Veneer Market Values per Cubic Foot of Block Volume, dollars.

Grade	Diameter, inches	$	Treatment	$	Day	$
AB	12	0.00	Hot	0.37	1	0.17
	18	0.24	Warm	0.18	2	0.06
	24	0.09	Cold	0.12	3	0.11
CD	12	2.10	Hot	2.16	1	1.65
	18	2.44	Warm	1.95	2	2.19
	24	1.77	Cold	2.21	3	2.47
Utility	24	0.17	Hot	0.19	1	0.17
	18	0.05	Warm	0.05	2	0.06
	24	0.17	Cold	0.05	3	0.06
Total	12	2.17	Hot	2.38	1	1.99
	18	2.73	Warm	2.17	2	2.30
	24	2.04	Cold	2.38	3	2.63

AB, and B, as previously mentioned. The significant diameter * treatment interaction shown for Utility grade is not deemed important since this value increase (10 cents) was determined mostly by defects in the 24 inch blocks peeled on the first day.

Treatments did not have significant effect on veneer value for any green veneer market item. The lack of A-grade material in the No. 3 Sawmill logs removed the basis of the veneer volume increase as reported by Grantham and Atherton (1959). The total value of blocks peeled hot was equal to the value of blocks peeled cold. The value added to the veneer by preheating is not present based on volume, grade, and veneer item recovery.

Annual Cost of Preheating. For a one lathe mill capable of producing 75 to 80 million square feet, 3/8 inch basis, the annual costs for a steam chest or a hot water bath heating system are $318,000 and $299,000, respectively, at a zero rate of return (ROI). The incremental difference between the systems is $14,000 annually in favor of the hot water baths at zero percent ROI. The economic analysis is detailed in Appendix B.

From Table 23 it can be seen that the incremental difference between the hot and cold peeled block is zero. There is no monetary basis to return the over one-quarter million dollar annual cost of preheating if peeling No. 3 Sawmill logs.

Recovery Necessary to Justify Preheating. The least annual cost of preheating for a mill producing 75 to 80 million square feet, 3/8 inch basis of veneer annually, was $299,000 for the hot water vat system. The recovery increase necessary to justify this expenditure can be calculated.

From the average market value of green veneer (Appendix Table B-1) and the percentage recovery for grade CD in the veneer items, a value of 1000 square feet of veneer based on No. 3 Sawmill logs can be determined as follows:

Value = (% full sheets) x (average CD full sheet value)

+ (% half sheets) x (average CD half sheet value)

+ (% random widths) x (average CD random width value)

Inserting the appropriate values:

Value = (50%) x ($34.83) + (30%) x ($31.81) + (20%) x (18.54)

= $30.67

Rounding to the nearest dollar, the average value of 1000 square feet of CD green Douglas-fir veneer is $31.

The recovery increase on an annual basis required by a mill to offset preheating costs would be:

$$\% \text{ increase} = \frac{\text{annual preheating cost}}{\text{veneer value per 1000 square feet}} \div \text{annual production 3/8 inch basis}$$

Substituting

$$\% \text{ increase} = \frac{299{,}000}{\$31/\text{M sq ft}} \div 75 \text{ MM sq ft}$$

$$= 12.9\%$$

Since there was no statistical differences between treatments, no basis for the necessary 12.9 percent yield increase exists.

VII. CONCLUSIONS

1. Preheating Douglas-fir No. 3 Sawmill logs prior to peeling had no statistical effect on veneer value, total veneer yield, grade yield, or veneer item yield when blocks were heated to a peel temperature ranging from 50° to $120^{\circ}F$. Based only on veneer market values, preheating Douglas-fir No. 3 sawmill logs prior to peeling did not appear economically feasible.

2. Block diameter has a highly significant effect on veneer value expressed as the value of the percentage of block volume recovered as marketable green veneer. Eighteen inch diameter blocks had the greatest total, grade, and full sheet recovery per unit volume. Twenty-four inch diameter blocks had the least recovery and value while 12 inch blocks were intermediate.

3. Veneer thickness variation is statistically different for 12, 18, and 24 inch diameter blocks in the range of temperatures peeled. Heat treatment did not improve veneer thickness variation.

4. The variability of temperature within blocks as recorded at the lathe suggest the effects of heating on veneer peeling would vary greatly for any one block.

5. The infrared temperature sensing device and the microprocessor based computer can be successfully implemented in the mill.

6. The equation for unsteady state heat transfer for an infinitely long cylinder may not be appropriate for wood when constrained by constant diffusivity and homogeneity.

Recommendations

One of the sub-objectives of the original study plan was to formulate a research plan for expanded but closely controlled mill studies of the peeling operation to include other species, log diameters, and possibly heating systems not previously covered. Based on experience gained during this study, further studies, regardless of species, log diameters, and heating systems, should incorporate measurements of veneer yield and peel quality, block temperatures and lathe settings at the time of peeling. Each of these physical parameters should be sensed, recorded, analyzed, and controlled via a computer based data acquisition system.

Veneer Yield and Quality

Veneer grade, item, and total recovery differences can be quantified and assigned monetary units for economic consideration without great difficulty. Data reduction should produce incremental differences between blocks on a percentage of block volume recovered for each veneer item and grade. Comparisons can then be made after the yield differences are converted into money units using either market prices as reported by the forest products weekly newsletters, or internally assigned values.

Veneer quality, which includes thickness variation, surface roughness, and lathe-check depth, presents a more difficult problem. Quantifying veneer (peel) quality is not easy, and furthermore, once these differences have been measured, the matter of assessing the incremental value of the differences remains. From this study, it is not clear how much time and effort should be expended on the measurement of veneer quality. Perhaps initial studies should concentrate on identifying veneer yield differences and then analyze if veneer quality has a potential effect on mill operation.

Block Temperature

The block temperature profiles as recorded at the lathe exhibited so much variation of temperature along the block radius that the effects of the heating on veneer peeling was suspect. Obviously, if block peel temperatures are to be a study variable, a measurement of block temperature is necessary to classify blocks according to their actual temperature at peeling. The infrared sensor with the data acquisition system proved to be a measurement method suited to the mill environment. It should be utilized in future studies. If covered vats for floating logs are to be studied, the infrared sensing at the lathe can give block temperatures where thermocouple instrumentation of the blocks during heating is impractical if not impossible.

Lathe Settings

The results of this study indicated a significant influence of block diameter on veneer yield and thickness variation. This observation was probably due to block diameter-lathe geometry interaction. Earlier mentioned research showed lathe settings can have an important effect on veneer yields. Therefore, to control future mill studies, lathe settings must be known and monitored if comparisons between peels are to be made. In of itself, lathe settings represent an area for more research at the mill level.

Computer Based Data Acquisition

To quantify mill operations as realistically as possible, studies should be run at close to normal practice as possible, i.e. at current mill capacity and production levels. This would require great effort to accurately grade, measure, and tally the veneer produced from the study blocks. Clearly, a computer based data acquisition system would simplify the task. Most veneer mills today employ automatic veneer clippers that can clip the veneer ribbon to maximize full sheet production of the upper veneer grades. These clippers could be instrumentated with the appropriate data acquisition system to provide a tally of veneer items, total veneer recovery, and veneer grade. Such a system would not only be of great research value but would also provide the cooperating mill with valuable information. An instrumented lathe could be tied into the clipper system to provide a measurement of veneer yield at a particular lathe setting. A well documented study would result that could be repeated until the designed statistical operating characteristics are achieved.

The problem of measuring veneer quality cannot be solved until adequate transducers are developed that accurately and repeatably reflect differences in the components of veneer quality. Block heating can be evaluated with a system similar to the one developed for this study.

With the advancement of technology, computers are less expensive and more powerful. Interfacing of computers to the phsyical environment is being simplified by the same technology. If computer based data acquisition systems were not feasible in the past due to technical or economic reasons, their deployment in scientific research should be re-examined. These research tools could then be modified to continuously monitor mill production.

Summary

Future mill studies of the peeling operation should be run at mill conditions to accurately measure veneer yields. A computer based data acquistion system monitoring block, lathe, and clipper conditions would allow such studies to be realistically implemented. At this time, the sensing of peel quality at production conditions is not possible. Measurement systems must be developed prior to the incorporation of veneer quality into actual mill studies.

The amount and frequency of sampling and the methods utilized to reduce and statistically analyze the mill study data would require careful planning and the close attention of a qualified industrial statistician.

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APPENDICES

APPENDIX A

Analysis of Variance Tables

Appendix A-1

Analysis of Variance Tables

for

Green Veneer Grade and Item

ANALYSIS OF VARIANCE FOR VARIABLE Full Sheets AB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	42.17556	21.0877778
TRT	2	61.85407	30.9270370
ERROR A	4	39.28815	9.8220370
DIAM	2	77.78741	38.8937037
TRT*DIAM	4	80.10074	20.0251852
ERROR B	12	181.74963	15.1458025
RESIDUAL	54	611.58667	11.3256790
CORRECTED TOTAL	80	1094.54222	13.6817778

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	61.85407	30.9270370	3.14874	NS
DENOMINATOR:	ERROR A	4	39.28815	9.8220370		
NUMERATOR:	DIAM	2	77.78741	38.8937037	2.56795	NS
DENOMINATOR:	ERROR B	12	181.74963	15.1458025		
NUMERATOR:	TRT*DIAM	4	80.10074	20.0251852	1.32216	NS
DENOMINATOR:	ERROR B	12	181.74963	15.1458025		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Full Sheets CD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	2564.2452	1282.12259
TRT	2	25.7874	12.89370
ERROR A	4	1113.3941	278.34852
DIAM	2	2803.5163	1401.75815
TRT*DIAM	4	1366.0185	341.50463
ERROR B	12	1237.1007	103.09173
RESIDUAL	54	21489.8000	397.95926
CORRECTED TOTAL	80	30599.8622	382.49828

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	25.7874	12.89370	0.04632	NS
DENOMINATOR:	ERROR A	4	1113.3941	278.34852		
NUMERATOR:	DIAM	2	2803.5163	1401.75815	13.59719	**
DENOMINATOR:	ERROR B	12	1237.1007	103.09173		
NUMERATOR:	TRT*DIAM	4	1366.0185	341.50463	3.31263	*
DENOMINATOR:	ERROR B	12	1237.1007	103.09173		

ANALYSIS OF VARIANCE FOR VARIABLE Full Sheets Utility

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	405.80840	202.904198
TRT	2	233.17506	116.587531
ERROR A	4	466.35012	116.587531
DIAM	2	168.83877	84.419383
TRT*DIAM	4	407.19086	101.797716
ERROR B	12	1152.05926	96.004938
RESIDUAL	54	1756.95333	32.536173
CORRECTED TOTAL	80	4590.37580	57.379698

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	233.17506	116.587531	1.00000	NS
DENOMINATOR:	ERROR A	4	466.35012	116.587531		
NUMERATOR:	DIAM	2	168.83877	84.419383	0.87932	NS
DENOMINATOR:	ERROR B	12	1152.05926	96.004938		
NUMERATOR:	TRT*DIAM	4	407.19086	101.797716	1.06034	NS
DENOMINATOR:	ERROR B	12	1152.05926	96.004938		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Half Sheets AB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	1.334321	0.6671605
TRT	2	43.283210	21.6416049
ERROR A	4	10.745679	2.6864198
DIAM	2	27.349136	13.6745679
TRT*DIAM	4	46.548642	11.6371605
ERROR B	12	30.480000	2.5400000
RESIDUAL	54	261.066667	4.8345679
CORRECTED TOTAL	80	420.807654	5.2600957

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	43.283210	21.6416049	8.05593	*
DENOMINATOR:	ERROR A	4	10.745679	2.6864198		
NUMERATOR:	DIAM	2	27.349136	13.6745679	5.38369	*
DENOMINATOR:	ERROR B	12	30.480000	2.5400000		
NUMERATOR:	TRT*DIAM	4	46.548642	11.6371605	4.58156	*
DENOMINATOR:	ERROR B	12	30.480000	2.5400000		

ANALYSIS OF VARIANCE FOR VARIABLE Half Sheets CD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	1049.45210	524.726049
TRT	2	987.76025	493.880123
ERROR A	4	112.44568	28.111420
DIAM	2	61.84617	30.923086
TRT*DIAM	4	446.43160	111.607901
ERROR B	12	1140.66667	95.055556
RESIDUAL	54	3632.82000	67.274444
CORRECTED TOTAL	80	7431.42247	92.892781

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	987.76025	493.880123	17.56867	*
DENOMINATOR:	ERROR A	4	112.44568	28.111420		
NUMERATOR:	DIAM	2	61.84617	30.923086	0.32532	NS
DENOMINATOR:	ERROR B	12	1140.66667	95.055556		
NUMERATOR:	TRT*DIAM	4	446.43160	111.607901	1.17413	NS
DENOMINATOR:	ERROR B	12	1140.66667	95.055556		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Half Sheets Utility

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	5.58099	2.7904938
TRT	2	90.43654	45.2182716
ERROR A	4	260.99160	65.2479012
DIAM	2	56.02247	28.0112346
TRT*DIAM	4	175.63012	43.9075309
ERROR B	12	752.17407	62.6811728
RESIDUAL	54	2859.58000	52.9551852
CORRECTED TOTAL	80	4200.41580	52.5051975

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	90.43654	45.2182716	0.69302	NS
DENOMINATOR:	ERROR A	4	260.99160	65.2479012		
NUMERATOR:	DIAM	2	56.02247	28.0112346	0.44688	NS
DENOMINATOR:	ERROR B	12	752.17407	62.6811728		
NUMERATOR:	TRT*DIAM	4	175.63012	43.9075309	0.70049	NS
DENOMINATOR:	ERROR B	12	752.17407	62.6811728		

STATISTICAL ANALYSIS SYSTEM

ANALYSIS OF VARIANCE FOR VARIABLE Random Widths AB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	22.240741	11.1203704
TRT	2	1.178519	0.5892593
ERROR A	4	3.194074	0.7985185
DIAM	2	11.166667	5.5833333
TRT*DIAM	4	4.510370	1.1275926
ERROR B	12	30.709630	2.5591358
RESIDUAL	54	75.920000	1.4059259
CORRECTED TOTAL	80	148.920000	1.8615000

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	1.178519	0.5892593	0.73794	NS
DENOMINATOR:	ERROR A	4	3.194074	0.7985185		
NUMERATOR:	DIAM	2	11.166667	5.5833333	2.18173	NS
DENOMINATOR:	ERROR B	12	30.709630	2.5591358		
NUMERATOR:	TRT*DIAM	4	4.510370	1.1275926	0.44061	NS
DENOMINATOR:	ERROR B	12	30.709630	2.5591358		

ANALYSIS OF VARIANCE FOR VARIABLE Random Widths CD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	349.74691	174.873457
TRT	2	257.36765	128.683827
ERROR A	4	545.77901	136.444753
DIAM	2	556.73506	278.367531
TRT*DIAM	4	378.37531	94.593827
ERROR B	12	1061.24519	88.437099
RESIDUAL	54	3170.37333	58.710617
CORRECTED TOTAL	80	6319.62247	78.995281

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	257.36765	128.683827	0.94312	NS
DENOMINATOR:	ERROR A	4	545.77901	136.444753		
NUMERATOR:	DIAM	2	556.73506	278.367531	3.14763	NS
DENOMINATOR:	ERROR B	12	1061.24519	88.437099		
NUMERATOR:	TRT*DIAM	4	378.37531	94.593827	1.06962	NS
DENOMINATOR:	ERROR B	12	1061.24519	88.437099		

STATISTICAL ANALYSIS SYSTEM

ANALYSIS OF VARIANCE FOR VARIABLE Random Widths Utility

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	3.645185	1.82259259
TRT	2	0.495556	0.24777778
ERROR A	4	5.581481	1.39537037
DIAM	2	2.168889	1.08444444
TRT*DIAM	4	2.393333	0.59833333
ERROR B	12	27.317778	2.27648148
RESIDUAL	54	83.006667	1.53716049
CORRECTED TOTAL	80	124.608889	1.55761111

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.495556	0.24777778	0.17757	NS
DENOMINATOR:	ERROR A	4	5.581481	1.39537037		
NUMERATOR:	DIAM	2	2.168889	1.08444444	0.47637	NS
DENOMINATOR:	ERROR B	12	27.317778	2.27648148		
NUMERATOR:	TRT*DIAM	4	2.393333	0.59833333	0.26283	NS
DENOMINATOR:	ERROR B	12	27.317778	2.27648148		

ANALYSIS OF VARIANCE FOR VARIABLE Fishtails AB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	4.5232099	2.26160494
TRT	2	0.0306173	0.01530864
ERROR A	4	1.0212346	0.25530864
DIAM	2	2.8476543	1.42382716
TRT*DIAM	4	0.4123457	0.10308642
ERROR B	12	4.8577778	0.40481481
RESIDUAL	54	15.4400000	0.28592593
CORRECTED TOTAL	80	29.1328395	0.36416049

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.0306173	0.01530864	0.05996	NS
DENOMINATOR:	ERROR A	4	1.0212346	0.25530864		
NUMERATOR:	DIAM	2	2.8476543	1.42382716	3.51723	NS
DENOMINATOR:	ERROR B	12	4.8577778	0.40481481		
NUMERATOR:	TRT*DIAM	4	0.4123457	0.10308642	0.25465	NS
DENOMINATOR:	ERROR B	12	4.8577778	0.40481481		

ANALYSIS OF VARIANCE FOR VARIABLE Fishtails CD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	0.256543	0.1282716
TRT	2	22.199506	11.0997531
ERROR A	4	10.292346	2.5730864
DIAM	2	34.078765	17.0393827
TRT*DIAM	4	38.359012	9.5897531
ERROR B	12	61.815556	5.1512963
RESIDUAL	54	390.773333	7.2365432
CORRECTED TOTAL	80	557.775062	6.9721883

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	22.199506	11.0997531	4.31379	NS
DENOMINATOR:	ERROR A	4	10.292346	2.5730864		
NUMERATOR:	DIAM	2	34.078765	17.0393827	3.30779	NS
DENOMINATOR:	ERROR B	12	61.815556	5.1512963		
NUMERATOR:	TRT*DIAM	4	38.359012	9.5897531	1.86162	NS
DENOMINATOR:	ERROR B	12	61.815556	5.1512963		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Fishtails Utility

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	2.5402469	1.27012346
TRT	2	0.2195062	0.10975309
ERROR A	4	1.9345679	0.48364198
DIAM	2	0.1958025	0.09790123
TRT*DIAM	4	1.1723457	0.29308642
ERROR B	12	4.3807407	0.36506173
RESIDUAL	54	8.2133333	0.15209877
CORRECTED TOTAL	80	18.6565432	0.23320679

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.2195062	0.10975309	0.22693	NS
DENOMINATOR:	ERROR A	4	1.9345679	0.48364198		
NUMERATOR:	DIAM	2	0.1958025	0.09790123	0.26818	NS
DENOMINATOR:	ERROR B	12	4.3807407	0.36506173		
NUMERATOR:	TRT*DIAM	4	1.1723457	0.29308642	0.80284	NS
DENOMINATOR:	ERROR B	12	4.3807407	0.36506173		

Appendix A-2

Analysis of Variance Tables

for

Veneer Grade

ANALYSIS OF VARIANCE FOR VARIABLE Veneer Grade A

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	171.95284	85.976420
TRT	2	37.52914	18.764568
ERROR A	4	69.06272	17.265679
DIAM	2	271.21284	135.606420
TRT*DIAM	4	38.50049	9.625123
ERROR B	12	531.09111	44.257593
RESIDUAL	54	1191.82667	22.070864
CORRECTED TOTAL	80	2311.17580	28.889698

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	37.52914	18.764568	1.08681	NS
DENOMINATOR:	ERROR A	4	69.06272	17.265679		
NUMERATOR:	DIAM	2	271.21284	135.606420	3.06403	NS
DENOMINATOR:	ERROR B	12	531.09111	44.257593		
NUMERATOR:	TRT*DIAM	4	38.50049	9.625123	0.21748	NS
DENOMINATOR:	ERROR B	12	531.09111	44.257593		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Veneer Grade AB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	8.820000	4.41000000
TRT	2	8.820000	4.41000000
ERROR A	4	17.640000	4.41000000
DIAM	2	2.649630	1.32481481
TRT*DIAM	4	5.299259	1.32481481
ERROR B	12	15.897778	1.32481481
RESIDUAL	54	102.573333	1.89950617
CORRECTED TOTAL	80	161.700000	2.02125000

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	8.820000	4.41000000	1.00000	NS
DENOMINATOR:	ERROR A	4	17.640000	4.41000000		
NUMERATOR:	DIAM	2	2.649630	1.32481481	1.00000	NS
DENOMINATOR:	ERROR B	12	15.897778	1.32481481		
NUMERATOR:	TRT*DIAM	4	5.299259	1.32481481	1.00000	NS
DENOMINATOR:	ERROR B	12	15.897778	1.32481481		

ANALYSIS OF VARIANCE FOR VARIABLE Veneer Grade B

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	6.4800000	3.24000000
TRT	2	5.3540741	2.67703704
ERROR A	4	10.7081481	2.67703704
DIAM	2	2.2866667	1.14333333
TRT*DIAM	4	4.7881481	1.19703704
ERROR B	12	14.1496296	1.17913580
RESIDUAL	54	10.7333333	0.19876543
CORRECTED TOTAL	80	54.5000000	0.68125000

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	5.3540741	2.67703704	1.00000	NS
DENOMINATOR:	ERROR A	4	10.7081481	2.67703704		
NUMERATOR:	DIAM	2	2.2866667	1.14333333	0.96964	NS
DENOMINATOR:	ERROR B	12	14.1496296	1.17913580		
NUMERATOR:	TRT*DIAM	4	4.7881481	1.19703704	1.01518	NS
DENOMINATOR:	ERROR B	12	14.1496296	1.17913580		

ANALYSIS OF VARIANCE FOR VARIABLE Veneer Grade C

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	2943.5696	1471.78481
TRT	2	8.0600	4.03000
ERROR A	4	1885.7593	471.43981
DIAM	2	3438.8289	1719.41444
TRT*DIAM	4	1556.4778	389.11944
ERROR B	12	4227.6733	352.30611
RESIDUAL	54	17101.3533	316.69173
CORRECTED TOTAL	80	31161.7222	389.52153

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	8.0600	4.03000	0.00855	NS
DENOMINATOR:	ERROR A	4	1885.7593	471.43981		
NUMERATOR:	DIAM	2	3438.8289	1719.41444	4.88046	*
DENOMINATOR:	ERROR B	12	4227.6733	352.30611		
NUMERATOR:	TRT*DIAM	4	1556.4778	389.11944	1.10449	NS
DENOMINATOR:	ERROR B	12	4227.6733	352.30611		

STATISTICAL ANALYSIS SYSTEM

ANALYSIS OF VARIANCE FOR VARIABLE Veneer Grade CD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	9244.3632	4622.18160
TRT	2	1149.6128	574.80642
ERROR A	4	680.6842	170.17105
DIAM	2	878.3336	439.16679
TRT*DIAM	4	2160.6516	540.16290
ERROR B	12	4903.5215	408.62679
RESIDUAL	54	11838.7867	219.23679
CORRECTED TOTAL	80	30855.9536	385.69942

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	1149.6128	574.80642	3.37782	NS
DENOMINATOR:	ERROR A	4	680.6842	170.17105		
NUMERATOR:	DIAM	2	878.3336	439.16679	1.07474	NS
DENOMINATOR:	ERROR B	12	4903.5215	408.62679		
NUMERATOR:	TRT*DIAM	4	2160.6516	540.16290	1.32190	NS
DENOMINATOR:	ERROR B	12	4903.5215	408.62679		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Veneer Grade Utility

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	457.69358	228.846790
TRT	2	649.74617	324.873086
ERROR A	4	782.16790	195.541975
DIAM	2	411.68469	205.842346
TRT*DIAM	4	1059.97679	264.994198
ERROR B	12	598.30741	49.858951
RESIDUAL	54	4736.23333	87.708025
CORRECTED TOTAL	80	8695.80988	108.697623

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	649.74617	324.873086	1.66140	NS
DENOMINATOR:	ERROR A	4	782.16790	195.541975		
NUMERATOR:	DIAM	2	411.68469	205.842346	4.12849	*
DENOMINATOR:	ERROR B	12	598.30741	49.858951		
NUMERATOR:	TRT*DIAM	4	1059.97679	264.994198	5.31488	*
DENOMINATOR:	ERROR B	12	598.30741	49.858951		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Veneer Grade Reject

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	0.5928395	0.296419753
TRT	2	0.1706173	0.085308642
ERROR A	4	0.3412346	0.085308642
DIAM	2	0.1706173	0.085308642
TRT*DIAM	4	0.7634568	0.190864198
ERROR B	12	1.8681481	0.155679012
RESIDUAL	54	8.4066667	0.155679012
CORRECTED TOTAL	80	12.3135802	0.153919753

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.1706173	0.085308642	1.00000	NS
DENOMINATOR:	ERROR A	4	0.3412346	0.085308642		
NUMERATOR:	DIAM	2	0.1706173	0.085308642	0.54798	NS
DENOMINATOR:	ERROR B	12	1.8681481	0.155679012		
NUMERATOR:	TRT*DIAM	4	0.7634568	0.190864198	1.22601	NS
DENOMINATOR:	ERROR B	12	1.8681481	0.155679012		

Appendix A-3

Analysis of Variance Tables

for

Veneer Item and Total Recovery

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Full Sheets

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	0.16097788	0.080488938
TRT	2	0.02950699	0.014753494
ERROR A	4	0.12960183	0.032400457
DIAM	2	0.27714669	0.138573346
TRT*DIAM	4	0.13066012	0.032665031
ERROR B	12	0.28487519	0.023739599
RESIDUAL	54	2.07726733	0.038467914
CORRECTED TOTAL	80	3.09003602	0.038625450

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.02950699	0.014753494	0.45535	NS
DENOMINATOR:	ERROR A	4	0.12960183	0.032400457		
NUMERATOR:	DIAM	2	0.27714669	0.138573346	5.83722	*
DENOMINATOR:	ERROR B	12	0.28487519	0.023739599		
NUMERATOR:	TRT*DIAM	4	0.13066012	0.032665031	1.37597	NS
DENOMINATOR:	ERROR B	12	0.28487519	0.023739599		

ANALYSIS OF VARIANCE FOR VARIABLE Half Sheets

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	0.12628763	0.0631438148
TRT	2	0.12841607	0.0642080370
ERROR A	4	0.05145741	0.0128643519
DIAM	2	0.02022963	0.0101148148
TRT*DIAM	4	0.10455585	0.0261389630
ERROR B	12	0.15670563	0.0130588025
RESIDUAL	54	0.71636000	0.0132659259
CORRECTED TOTAL	80	1.30401222	0.0163001528

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.12841607	0.0642080370	4.99116	NS
DENOMINATOR:	ERROR A	4	0.05145741	0.0128643519		
NUMERATOR:	DIAM	2	0.02022963	0.0101148148	0.77456	NS
DENOMINATOR:	ERROR B	12	0.15670563	0.0130588025		
NUMERATOR:	TRT*DIAM	4	0.10455585	0.0261389630	2.00164	NS
DENOMINATOR:	ERROR B	12	0.15670563	0.0130588025		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Random Widths

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	0.015306247	0.0076531235
TRT	2	0.024299728	0.0121498642
ERROR A	4	0.053910346	0.0134775864
DIAM	2	0.051773654	0.0258868272
TRT*DIAM	4	0.036044938	0.0090112346
ERROR B	12	0.096560963	0.0080467469
RESIDUAL	54	0.334317333	0.0061910617
CORRECTED TOTAL	80	0.612213210	0.0076526651

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.024299728	0.0121498642	0.90149	NS
DENOMINATOR:	ERROR A	4	0.053910346	0.0134775864		
NUMERATOR:	DIAM	2	0.051773654	0.0258868272	3.21705	NS
DENOMINATOR:	ERROR B	12	0.096560963	0.0080467469		
NUMERATOR:	TRT*DIAM	4	0.036044938	0.0090112346	1.11986	NS
DENOMINATOR:	ERROR B	12	0.096560963	0.0080467469		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Total Recovery

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	0.30603291	0.153016457
TRT	2	0.18384817	0.091924086
ERROR A	4	0.08586657	0.021466642
DIAM	2	0.27658254	0.138291272
TRT*DIAM	4	0.03657516	0.009143790
ERROR B	12	0.19647652	0.016373043
RESIDUAL	54	1.90038067	0.035192235
CORRECTED TOTAL	80	2.98576254	0.037322032

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.18384817	0.091924086	4.28218	NS
DENOMINATOR:	ERROR A	4	0.08586657	0.021466642		
NUMERATOR:	DIAM	2	0.27658254	0.138291272	8.44628	*
DENOMINATOR:	ERROR B	12	0.19647652	0.016373043		
NUMERATOR:	TRT*DIAM	4	0.03657516	0.009143790	0.55847	NS
DENOMINATOR:	ERROR B	12	0.19647652	0.016373043		

Appendix A-4

Analysis of Variance Table

for

Veneer Thickness

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Thickness

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	0.00006065687	0.00003032844
TRT	2	0.00000001671	0.00000000836
ERROR A	4	0.00001250637	0.00000312659
DIAM	2	0.00003197385	0.00001598692
TRT*DIAM	4	0.00000603775	0.00000150944
ERROR B	12	0.00002918636	0.00000243220
CORRECTED TOTAL	26	0.00014037792	0.00000539915

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.00000001671	0.00000000836	0.00267	NS
DENOMINATOR:	ERROR A	4	0.00001250637	0.00000312659		
NUMERATOR:	DIAM	2	0.00003197385	0.00001598692	6.57304	*
DENOMINATOR:	ERROR B	12	0.00002918636	0.00000243220		
NUMERATOR:	TRT*DIAM	4	0.00000603775	0.00000150944	0.62061	NS
DENOMINATOR:	ERROR B	12	0.00002918636	0.00000243220		

Appendix A-5

Analysis of Variance Tables

for

Green Veneer Market Value

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Green Veneer Market Item AB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	0.15665020	0.078325101
TRT	2	0.26870618	0.134353091
ERROR A	4	0.10221367	0.025553416
DIAM	2	0.81188504	0.405942522
TRT*DIAM	4	0.20218480	0.050546199
ERROR B	12	1.15978784	0.096648986
RESIDUAL	54	4.32587399	0.080108778
CORRECTED TOTAL	80	7.02730172	0.087841272

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.26870618	0.134353091	5.25773	NS
DENOMINATOR:	ERROR A	4	0.10221367	0.025553416		
NUMERATOR:	DIAM	2	0.81188504	0.405942522	4.20017	*
DENOMINATOR:	ERROR B	12	1.15978784	0.096648986		
NUMERATOR:	TRT*DIAM	4	0.20218480	0.050546199	0.52299	NS
DENOMINATOR:	ERROR B	12	1.15978784	0.096648986		

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE FOR VARIABLE Green Veneer Market Item CD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	9.2160275	4.60801375
TRT	2	1.0330732	0.51653662
ERROR A	4	1.7923018	0.44807545
DIAM	2	5.9936543	2.99682714
TRT*DIAM	4	1.5763586	0.39408966
ERROR B	12	2.0530980	0.17109150
RESIDUAL	54	33.1249032	0.61342413
CORRECTED TOTAL	80	54.7894167	0.68486771

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	1.0330732	0.51653662	1.15279	NS
DENOMINATOR:	ERROR A	4	1.7923018	0.44807545		
NUMERATOR:	DIAM	2	5.9936543	2.99682714	17.51593	**
DENOMINATOR:	ERROR B	12	2.0530980	0.17109150		
NUMERATOR:	TRT*DIAM	4	1.5763586	0.39408966	2.30339	NS
DENOMINATOR:	ERROR B	12	2.0530980	0.17109150		

ANALYSIS OF VARIANCE FOR VARIABLE Green Veneer Market Item Utility

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	0.24044156	0.120220778
TRT	2	0.35356980	0.176784898
ERROR A	4	0.41555895	0.103889737
DIAM	2	0.23004368	0.115021839
TRT*DIAM	4	0.61673496	0.154183739
ERROR B	12	0.38674364	0.032228636
RESIDUAL	54	2.56235317	0.047450985
CORRECTED TOTAL	80	4.80544574	0.060068072

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.35356980	0.176784898	1.70166	NS
DENOMINATOR:	ERROR A	4	0.41555895	0.103889737		
NUMERATOR:	DIAM	2	0.23004368	0.115021839	3.56893	*
DENOMINATOR:	ERROR B	12	0.38674364	0.032228636		
NUMERATOR:	TRT*DIAM	4	0.61673496	0.154183739	4.78406	*
DENOMINATOR:	ERROR B	12	0.38674364	0.032228636		

ANALYSIS OF VARIANCE FOR VARIABLE Green Veneer Market Item Total

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
DAY	2	5.5762541	2.78812707
TRT	2	0.7653575	0.38267875
ERROR A	4	1.4061439	0.35153597
DIAM	2	7.3414313	3.67071564
TRT*DIAM	4	0.7590855	0.18977136
ERROR B	12	3.5668755	0.29723962
RESIDUAL	54	30.6425187	0.56745405
CORRECTED TOTAL	80	50.0576664	0.62572083

TESTS	SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	
NUMERATOR:	TRT	2	0.7653575	0.38267875	1.08859	NS
DENOMINATOR:	ERROR A	4	1.4061439	0.35153597		
NUMERATOR:	DIAM	2	7.3414313	3.67071564	12.34935	**
DENOMINATOR:	ERROR B	12	3.5668755	0.29723962		
NUMERATOR:	TRT*DIAM	4	0.7590855	0.18977136	0.63845	NS
DENOMINATOR:	ERROR B	12	3.5668755	0.29723962		

APPENDIX B

Economic Analysis

Table B-1. Green Veneer Market Prices (FOB Mill), January 1, 1978 to March 31, 1978.

		$ per 1000 sq. ft.			
Grade	Item	Low	High	Range	Mean
AB	Full	57.50	58.50	1.00	58.23
	Half	55.50	56.50	1.00	56.23
CD	Full	33.25	35.50	2.25	34.83
	Half	29.00	31.50	2.50	30.81
	Random	16.75	20.00	3.25	18.54
	Fishtail	11.50	17.50	6.00	14.21
Utility	Half	18.25	20.00	3.75	18.58
	Random	13.00	16.00	3.00	14.19

Economic Analysis

Cost estimates used in the analysis were obtained from a variety of sources. Bonney, Bennett & Peters, Consulting Engineers, Eugene, Oregon, provided the construction cost estimates. The industrial survey was used to estimate annual operating expenses. Discussions with mill personnel of various firms gave insight into production levels and costs associated with preheating.

Since the results of this study indicated vener value was not increased by preheating, a rate of return (ROI) of zero percent was assumed to find the recovery increase where preheating would begin to pay for itself on an annual capital cost (CR) basis.

Annual operating costs were calculated for hot water vat (2) and steam chest (8) systems adequate for a mill producing 75 to 80 million square feet of veneer annually. The systems correspond to the covered vats for floating logs and steam chest with steam injection described earlier. Costs are for the western Oregon region.

I. Steam Chest Construction Cost Estimate

A. First Cost

1.	Site work	$ 2,000
2.	Concrete, Installed	149,640
3.	Doors, Vents, Hardware	12,000
4.	Boiler, Installed	34,800
5.	Piping: Heat Exchanger, Water Recirculation for Steam and Condensate	50,000
6.	Electrical	50,000
7.	Mobil Equipment	70,000
8.	Engineering	15,000
	Subtotal	$382,440
	10% Contingency	38,244
	Total Cost	$420,644

B. Annual Cost

Assumptions:
Life Expectancy 7 years
Salvage Value 0

1. 0% ROI

$$CR = \frac{\text{(first cost - salvage value)}}{\text{life expectancy}}$$

$$= \frac{(\$420,644 - \$0)}{7 \text{ years}}$$

CR = $60,092/year

II. Hot Water Vat Construction Cost Estimate

A. First Cost

1.	Concrete	$120,000
2.	Control Houses, 2 Required	15,220
3.	Water Storage, 1 Tank	46,000
4.	Piping: Heat Exchanger, Pumps, Valves, Screens, Piping	131,500
5.	Mechanical Equipment: 2 Block Transfer Systems, 2 Jackladders, Outfeed Conveyor (60 feet), Walks and Stairs, Miscellaneous Steel	199,930
6.	Engineering	15,000
	Subtotal	$527,630
	10% Contingency	52,763
	Total Cost	$580,393

B. Annual Cost

Assumptions:
Life Expectancy 7 years
Salvage Value 0

1. 0% ROI

$$CR = \frac{\text{(first cost - salvage value)}}{\text{life expectancy}}$$

$$= \frac{(\$580,393 - \$0)}{7 \text{ years}}$$

CR = $82,913/year

III. Annual Operating Expenses

It was assumed that the heat reuqirements of both systems would be 10 million BTU per year. One million BTU was assumed to cost $2.25. Maintenance costs were fixed at ten percent of fixed cost.

A. Steam Chest

1.	Chest Maintenance, Mobile Equipment Included	$ 42,064
2.	Block Heating	108,000

$$\frac{10\text{ MM BTU}}{\text{year}} * \frac{240\text{ days}}{\text{year}} * \frac{20\text{ hours}}{\text{day}} * \frac{\$2.25}{\text{MM BTU}}$$

3.	Mobile Equipment Operation	57,600

$$\frac{240\text{ days}}{\text{year}} * \frac{20\text{ hours}}{\text{day}} * \frac{\$12}{\text{hour}}$$

4.	Manpower (2 men)	50,000
	Total Cost	$257,664

B. Hot Water Vats

1.	Vat Maintenance, Material Handling Equipment Included	$ 58,039
2.	Block Heating	50,000
	Total Cost	$216,039

IV. Total Annual Cost

A. Steam Chests

1. 0% ROI

Capital Recovery	$ 60,092
Operating Expense	257,664
Total Annual Cost	$317,756

B. Hot Water Vats

1. 0% ROI

Capital Recovery	$ 82,913
Operating Expense	$216,039
Total Annual Cost	$298,952

APPENDIX C

Questionnaire

QUESTIONNAIRE

BENEFITS OF HEATING VENEER BOLTS PRIOR TO PEELING

1. General Questions

Do you heat your bolts prior to peeling?

What benefits, if any, are obtained by preheating?

Do these benefits outweigh costs (by how much)?

Do you sort prior to heating (by species, log grade, log diameter, frozen logs)?

What is the desired temperature at the core (or other depth) for these sorts?

What are your heating cycles for each sorted class?

What do you think is the temperature at the lathe? ____________________

What is the surface temperature after round-up? ____________________

What is the temperature of the core after peeling? ____________________

What is the temperature of the steam or water in your vat? ____________________

2. Description of Heating System

What type of system are you using (hotwater bath, steam spray, continuous or batch system, etc.)?

How many vats do you use?

What are their dimensions (length, width, height)?

What is their capacity (size of charge)?

Number of vats in use at any one time?

What is their construction (a sketch would be welcomed on facing page)?

Doors or covers?

Vat walls?

Location and size of vents, and intake holes?

How are the vats cleaned?

How often do you clean them and what is done with the residue?

Do you have Ph control of process water?

Is your heating medium being circulated? Please describe.

What is your temperature control? (instrumentation used?)

Where is the temperature sensor located?

Are the controls always functional?

How do you make sure that the temperature is maintained at the desired level?

How much steam/water is consumed per charge to raise the vat temperature to the desired temperature?

How much steam/water is needed to maintain the desired temperature?

How much condensate/waste process water is produced per charge, and how is it disposed?

3. Lathe Operation

Which thicknesses do you peel?

Do you peel 8ft as well as 4ft blocks?

To what core size do you peel?

At what speed do you peel?

What are your lathe settings for each thickness peeled?:

Horizontal nosebar opening?

Nosebar clearance?

Knife tips above center?

What is the knife setting:

Knife angle?

Back bevel?

How often is the knife sharpened?

How many times can any one knife be sharpened?

How long does it take to remove and replace the knife for sharpening?

Do you know the horsepower required for your lathe?

How many spin-outs do you experience per shift?

How many split-outs do you have per shift?

4. Materials Handling (Please give rough sketch)

What is your method of loading the charger?

What is the time needed to load/unload your vat?

How many men are required to load the vats?

How much time passes between opening of the vat and peeling on the lathe?

What is the number of charges per vat per day?

5. Costs

What is the original cost of constructing your vat?

When were they constructed?

What is the life expectancy of vats?

What does it cost to maintain your vats?

What was the original cost for your materials handling equipment?

What is the maintenance cost for this equipment?

What do you have to pay for manpower:

Loading personnel?

Maintenance people?

Systems support like lathe maintenance, knife grinding, etc.?

6. Additional questions

Please describe any part of your preconditioning system you feel is unusual (evaporators, heat exchangers, circulation systems, material handling, etc.) and their advantages or disadvantages.

To what extent does your preconditioning increase your veneer yield, if at all?

Please name problems with preheating, such as log degrade, accidents, etc.

Do you think that future pollution standards on discharge will affect you and what shall be done about them?

What improvements would you like to see in your system?

Do you have any studies you have done on the benefits of preheating? If so, could we share them with you?

APENDIX D

Block Heating Simulation Program and Sample Output

```
C     SIMULATION OF LOGHEATING
C
C     PROGRAM REQUIRES INPUT CARDS WITH THE FOLLOWING INFORMATION
C     CARD NO.  FIELD NO.  COLUMN    FORMAT   VARIABLE NAME
C
C       1          1         1-10     F10.5     DELT
C                  2        11-20     F10.5     DELTR
C
C       2          1         1-4       I4       RADIUS
C                  2        10-13      I4       DEPTH
C                  3        20-29     F9.0      TDONE
C                  4        30-40     F10.6     DIFF
C
C       3          1         1-6      F6.2      TMED
C                  2         8-13     F6.2      TNITAL
C                  3        15-20     F6.2      TCRIT
C                  4        22-23      I2       PRNT
C                  5        25-26      I2       IPLOT
C
C     VARIABLES IN THE PROGRAM HAVE THE FOLLOWING MEANING
C
C     DELT      TIME STEP, IN SECONDS
C     DELTR     DISTANCE BETWEEN NODES
C     DEPTH     DISTANCE FROM CENTER FOR DESIRED TEMPERATURE
C     DIFF      DIFFUSIVITY, IN.**2/SECONDS
C     HRS       TIME IN HOURS FROM BEGINNING OF SIMULATION
C     IPLOT     -1 IF PLOT IS NOT DESIRED
C               1-99 FREQUENCY OF PLOT LINES
C     PRNT      FREQUENCY TO PRINT TIME, TEMPERATURE RESULTS
C     RADIUS    RADIUS OF LOG TO BE HEATED
C     TCRIT     DESIRED TEMPERATURE OF LOG AT DEPTH SPECIFIED
C     TDONE     TIME OUT, IN SECONDS
C     TEMP      TEMPERATURE ARRAY
C     TIME      TIME IN SECONDS FROM START OF SIMULATION
C     TMED      TEMPERATURE OF MEDIUM SURROUNDING THE LOG
C     TNITAL    INITIAL LOG TEMPERATURE
C
C     OUTPUT INFORMATION
C
C     TAPE2     DECK TO BE PUNCHED FOR HP PLOTTER
C
C     TAPE3     LINE PRINTER OUTPUT
C
C     PROGRAM IS A FLECS SOURCE DECK
C     MUST BE TRANSLATED BEFORE EXECUTION
C
C     ******************************************************
C
      PROGRAM LOG(TAPE1,TAPE2,TAPE3,OUTPUT,TAPE6=OUTPUT)
      COMMON/BLOCK1/TEMP(60),DELT,DTEMP(60)
      COMMON/BLOCK2/NODE
      COMMON/BLOCK3/DIFF,DELTR,INCR
      COMMON/BLOCK4/ TI1(60),TI2(60),TI3(60),TDI1(60),TDI2(60),TDI3(60)
      REAL DIFF,DELT,DELTR,TMED,TNITAL,TCRIT,TIME
      INTEGER NODE,RADIUS,INCR,DEPTH,PRNT
      LOGICAL DONE
C
C     FLECS PROCEDURE
C
```

```
      INPUT-READ-RUN-PARAMETERS
      INPUT-READ-LOG-PARAMETERS
      INPUT-READ-TEMPERATURE-PARAMETERS
      SET-UP-NODE-POINTS
      INITILIZE-LOG-TEMPERATURE
      PAGE-HEADINGS
      OUTPUT-RESULTS
      PUNCH-DECK-FOR-PLOTS
      REPEAT UNTIL(DONE)
      .  CHECK-TEMPERATURE-SET-DONE
      .  WHEN(.NOT.DONE)
      .  .  COMPUTE-DT
      .  .  COMPUTE-NEW-VALUE
      .  .  COMPUTE-CENTER
      .  .  INCREMENT-TIME
      .  .  OUTPUT-RESULTS
      .  .  PUNCH-DECK-FOR-PLOTS
      .  ...FIN
      .  ELSE
      .  .  OUTPUT-RESULTS
      .  .  PUNCH-DECK-FOR-PLOTS
      .  .  PRINT-SUMMARY
      .  ...FIN
      ...FIN
      REWIND 1
      REWIND 2
      REWIND 3
      STOP

  ----------------------------------------

      TO CHECK-TEMPERATURE-SET-DONE
      .  DONE=TIME.GE.TDONE.OR.TEMP(DEPTH).GE.TCRIT
C     .
C     .  SET COUNTERS FOR OUPUT
C     .
      .  IF (DONE)
      .  .  CONDITIONAL
      .  .  .  (LPRT.NE.0)LPRT=PRNT
      .  .  ...FIN
      .  .  CONDITIONAL
      .  .  .  (PLOT.NE.0)PLOT=IPLOT
      .  .  ...FIN
      .  ...FIN
      ...FIN

  ----------------------------------------

      TO COMPUTE-DT
C     .
C     .  ASSUME OUTSIDE OF LOG REACHES TMED IMMEDIATELY
C     .
      .  TEMP(INCR+1)=TI1(INCR+1)=TI2(INCR+1)=TI3(INCR+1)=TMED
      .  DO(NODE=2,INCR)
      .  .  CALL TDOT(TEMP,DTEMP)
      .  ...FIN
      ...FIN

  ----------------------------------------

      TO COMPUTE-NEW-VALUE
      .  DO(NODE=2,INCR)
      .  .  CALL INTGRL
```

```
        .  ...FIN
        ...FIN

   ---------------------------------------

        TO INPUT-READ-RUN-PARAMETERS
        .  READ(1,100)DELT,DELTR
   100  .  FORMAT(2(F10.5,1X))
        ...FIN

   ---------------------------------------

        TO INPUT-READ-LOG-PARAMETERS
        .  READ(1,110) RADIUS,DEPTH,TDONE,DIFF
   110  .  FORMAT(I4,T10,I4,T20,F9.0,T30,F10.6)
        ...FIN

   ---------------------------------------

        TO INPUT-READ-TEMPERATURE-PARAMETERS
        .  READ(1,120) TMED,TNITAL,TCRIT,PRNT,IPLOT
   120  .  FORMAT(3(F6.2,1X),I2,1X,I2)
        .  IF(IPLOT.NE.-1)
        .  .  WRITE(2,100)DELT,DELTR
        .  .  WRITE(2,110)RADIUS,DEPTH,TDONE,DIFF
        .  .  WRITE(2,120)TMED,TNITAL,TCRIT,PRNT,IPLOT
        .  ...FIN
        ...FIN

   ---------------------------------------

        TO INITILIZE-LOG-TEMPERATURE
        .  TIME=0.0
        .  K=INCR+1
        .  DO(NODE=1,K)
        .  .  TEMP(NODE)=TI1(NODE)=TI2(NODE)=TI3(NODE)=TNITAL
        .  ...FIN
 C      .
 C      .  TO PRINT THE PROPER NUMBER OF NODES AND INITIAL TEMPERATURE
 C      .
        .  NODE=NODE-1
        .  LPRT=PRNT
        .  PLOT=IPLOT
        ...FIN

   ---------------------------------------

        TO INCREMENT-TIME
        .  TIME=TIME+DELT
        .  HRS=TIME/3600.
        ...FIN

   ---------------------------------------

        TO PRINT-SUMMARY
        .  WRITE(3,230)DELT,DELTR,RADIUS,NODE,TDONE,PRNT
        .  WRITE(3,240)DEPTH,TCRIT,TMED,TNITAL
   230  .  FORMAT(1H1/,1HS,//,5X,24H---- RUN PARAMETERS ----,/,/,
      1.   10X,10HTIME STEP ,F4.0,5H SEC.,/,
      2.   10X,27HDISTANCE BETWEEN THE NODES ,F6.2,4H IN.,/,
      3.   10X,18HRADIUS OF THE LOG ,I4,4H IN.,/,
      4.   10X,10HTHERE ARE ,I2,7H NODES,/,
      5.   10X,*TIME OUT *,F9.0,* SEC. *,/
```

```
         6.  .10X,≠RESULT PRINT FREQUENCY ≠,I2,//)
   240   .   FORMAT(1X,31HTHE SIMULATION TERMINATED WHEN≠,/,/,
         1.  1X,16HTHE TEMPERATURE ,I2,≠ INCHES FROM CENTER WAS AT≠,
         2.  ,7H LEAST ,F6.2,10H DEGREES F,/,
         3.  1X,27HTHE MEDIUM TEMPERATURE WAS ,F7.2,10H DEGREES F,/,
         4.  1X,32HTHE INITIAL LOG TEMPERATURE WAS ,F7,2,10H DEGREES F)
         .   WRITE(3,220)HRS,TEMP(1),DEPTH,TEMP(DEPTH),DELTP,TEMP(RADIUS)
   220   .   FORMAT(1X,≠TIME IN HRS ≠,F7.3/,1X,≠TEMPERATURE AT CENTER ≠.
         1.  F7.2/,1X,≠TEMPERATURE ≠,I2,≠ INCHES FROM CENTER ≠,F7.2
         2.  ,≠ DEGREES F≠/,
         3.  1X,≠TEMPERATURE ≠,F6.2,≠ INCH BELOW THE SURFACE ≠,F7.2,
         4.  ≠ DEGREES F≠//)
 C       .
 C       .   LAST CARD FOR PUNCHED DECK
 C       .
         .   IF(IPLOT.NE.-1)
         .   .  WRITE(2,420)-999.9
   420   .   .  FORMAT(F6.1)
         .   ...FIN
         ...FIN

     ----------------------------------------

         TO OUTPUT-RESULTS
         .   WHEN(LPRT.EQ.PRNT)
         .   .  LPRT=0
         .   .  CONDITIONAL
         .   .  .  (NODE.LE.12)WRT=1
         .   .  .  (OTHERWISE)WRT=2
         .   .  ...FIN
         .   .  CONDITIONAL
         .   .  .  (WRT.EQ.1)
         .   .  .  .  WRITE(3,300)HRS,(TEMP(I),I=1,NODE)
         .   .  .  ...FIN
         .   .  .  (WRT.EQ.2)
         .   .  .  .  WRITE(3,300)HRS,(TEMP(I),I=1,12)
         .   .  .  .  WRITE(3,310)(TEMP(I),I=13,NODE)
         .   .  .  ...FIN
         .   .  ...FIN
   300   .   .  FORMAT(T2,F7.3,T10,12(F9.2,1X))
   310   .   .  FORMAT(T20,12(F9.2,1X))
         .   ...FIN
         .   ELSE
         .   .  LPRT=LPRT+1
         .   ...FIN
         ...FIN

     ----------------------------------------

         TO SET-UP-NODE-POINTS
         .   RAD=0.0
         .   NODE=INCR=0
         .   UNTIL(RAD.GE.RADIUS)
         .   .  RAD=RAD+DELTR
         .   .  INCR=INCR+1
         .   ...FIN
         ...FIN

     ----------------------------------------

         TO COMPUTE-CENTER
         .   TEMP(1)=(TEMP(2)*4./3.)-(TEMP(3)/3.)
         ...FIN
```

```
-----------------------------------------

00213          TO PAGE-HEADINGS
00214          .  WRITE(3,500)
00215          .  WRITE(3,510)DELTR
00216    500 . FORMAT(1H1,/,1HT//,30X,≠-----TIME AND TEMPERATURE-----≠,///,1HT)
00217    510 . FORMAT(T4,≠TIME≠,T13,≠CENTER≠,T41,≠NODES ≠,F6.2,≠ INCHES APART≠
00218      1.  ,/T3,≠(HRS.)≠,T14,≠(F)≠,T53,≠(F)≠/)
00219          ...FIN

-----------------------------------------

00220          TO PUNCH-DECK-FOR-PLOTS
00221          .  IF(IPLOT.NE.-1)
00222          .  .  WHEN(IPLOT.EQ.PLOT)
00223          .  .  .  PLOT=0
00224          .  .  .  CONDITIONAL
00225          .  .  .  .  (NODE.LE.7) PC=1
00226          .  .  .  .  (NODE.LE.15) PC=2
00227          .  .  .  .  (OTHERWISE)PC=3
00228          .  .  .  ...FIN
00229          .  .  .  CONDITIONAL
00230          .  .  .  .  (PC.EQ.1)
00231          .  .  .  .  .  WRITE(2,400)HRS,(TEMP(I),I=1,NODE)
00232          .  .  .  .  ...FIN
00233          .  .  .  .  (PC.EQ.2)
00234          .  .  .  .  .  WRITE(2,400)HRS,(TEMP(I),I=1,7)
00235          .  .  .  .  .  WRITE(2,410)(TEMP(I),I=8,NODE)
00236          .  .  .  .  ...FIN
00237          .  .  .  .  (PC.EQ.3)
00238          .  .  .  .  .  WRITE(2,400)HRS,(TEMP(I),I=1,7)
00239          .  .  .  .  .  WRITE(2,410)(TEMP(I),I=8,15)
00240          .  .  .  .  .  WRITE(2,410)(TEMP(I),I=15,NODE)
00241          .  .  .  .  ...FIN
00242          .  .  .  ...FIN
00243          .  .  ...FIN
00244          .  .  ELSE
00245          .  .  .  PLOT=PLOT+1
00246          .  .  ...FIN
00247          .  ...FIN
00248    400 . FORMAT(F7.3,2X,7(F7.2,1X))
00249    410 . FORMAT(8(F7.2,1X))
00250          ...FIN
00251          END

-----------------------------------------
```

PROCEDURE CROSS-REFERENCE TABLE

```
00068 CHECK-TEMPERATURE-SET-DONE
      00069

00210 COMPUTE-CENTER
      00073

00162 COMPUTE-DT
      00071

00111 COMPUTE-NEW-VALUE
      00072

[illegible] INCREMENT-TIME
```

```
      00074

00133 INITILIZE-LOG-TEMPERATURE
      00064

00120 INPUT-READ-LOG-PARAMETERS
      00061

00116 INPUT-READ-RUN-PARAMETERS
      00060

00124 INPUT-READ-TEMPERATURE-PARAMETERS
      00062

00179 OUTPUT-RESULTS
      00066  00075  00079

00213 PAGE-HEADINGS
      00065

00150 PRINT-SUMMARY
      00081

00220 PUNCH-DECK-FOR-PLOTS
      00067  00076  00080

00202 SET-UP-NODE-POINTS
      00063


(FLECS VERSION 22.51)
```

FLECS 78/07/19. 22.45.18.

```
      SUBROUTINE TDOT(T,DT)
      COMMON/BLOCK2/NODE
      COMMON/BLOCK3/DIFF,DELTR,INCR
      REAL T(60),DT(60)
      INTEGER DEQ
C
C     FLECS PROCEDURE
C
      CHECK-NODE-SET-DEQ-EQUATION-CHOICE
      COMPUTE-PROPER-DERIVATIVE
      RETURN
      ----------------------------------------

      TO CHECK-NODE-SET-DEQ-EQUATION-CHOICE
      .  CONDITIONAL
      .  .  (NODE.EQ.2) DEQ=1
      .  .  (NODE.GT.2.AND.NODE.LE.(INCR-1)) DEQ=2
      .  .  (OTHERWISE) DEQ=3
      .  ...FIN
      ...FIN

      ----------------------------------------

      TO COMPUTE-PROPER-DERIVATIVE
      .  CONDITIONAL
C     .  .
C     .  .  FOR NODE 1
C     .  .
      .  .  (DEQ.EQ.1)
      .  .  .  DT(NODE)=(DIFF/(DELTR**2.))*((T(NODE)*(-4./3.))
     1.  .  .  +(T(NODE+1)*4./3 .))
      .  .  ...FIN
C     .  .
C     .  .  FOR NODE 2 TO NR-2
C     .  .
      .  .  (DEQ.EQ.2)
      .  .  .  I=NODE-1
      .  .  .  A=FLOAT(I)
      .  .  .  AA=((2.*A)-1.)/(2.*A)
      .  .  .  BB=((2.*A)+1.)/(2.*A)
      .  .  .  DT(NODE)=(DIFF/(DELTR**2.))*(((AA*T(NODE-1))
     1.  .  .  +(BB*T(NODE+1)))
     2.  .  .  +(-2.*T(NODE)))
      .  .  ...FIN
C     .  .
C     .  .  FOR NODE NR-1
C     .  .
      .  .  (DEQ.EQ.3)
      .  .  .  A=FLOAT(NODE)
      .  .  .  AA=((2.*A)-3.)/(2.*(A-1.))
      .  .  .  BB=((2.*A)-1.)/(2.*(A-1.))
      .  .  .  DT(NODE)=(DIFF/(DELTR**2.))*(((AA*T(NODE-1))
     1.  .  .  +(BB*T(NODE+1)))+(-2.*T(NODE)))
      .  .  ...FIN
      .  ...FIN
      ...FIN
      END
```

```
------------------------------------------

      PROCEDURE CROSS-REFERENCE TABLE

00263 CHECK-NODE-SET-DEQ-EQUATION-CHOICE
      00260

00270 COMPUTE-PROPER-DERIVATIVE
      00261

(FLECS VERSION 22.51)
```

```
      SUBROUTINE INTGRL
      COMMON/BLOCK1/TEMP(60),DELT,DTEMP(60)
      COMMON/BLOCK2/NODE
      COMMON/BLOCK4/ TI1(60),TI2(60),TI3(60),TDI1(60),TDI2(60),TDI3(60)
C
C      FLECS PROCEDURE
C
      COMPUTE-HOT-SDT
      COMPUTE-FIRST-LEVEL-INTEGRAL
      CALL-TDOT-FOR-FIRST-LEVEL
      COMPUTE-SECOND-LEVEL-INTEGRAL
      CALL-TDOT-FOR-SECOND-LEVEL
      COMPUTE-THIRD-LEVEL-INTEGRAL
      CALL-TDOT-FOR-THIRD-LEVEL
      COMPUTE-NEW-VALUE
      RETURN

-------------------------------------------

      TO COMPUTE-HOT-SDT
      .  HOT=DELT/2.
      .  SDT=DELT/6.
      ...FIN

-------------------------------------------

      TO COMPUTE-FIRST-LEVEL-INTEGRAL
      .  TI1(NODE)=TEMP(NODE)+HOT*DTEMP(NODE)
      ...FIN

-------------------------------------------

      TO COMPUTE-SECOND-LEVEL-INTEGRAL
      .  TI2(NODE)=TEMP(NODE)+HOT*TDI1(NODE)
      ...FIN

-------------------------------------------

      TO COMPUTE-THIRD-LEVEL-INTEGRAL
      .  TI3(NODE)=TEMP(NODE)+DELT*TDI2(NODE)
      ...FIN

-------------------------------------------

      TO COMPUTE-NEW-VALUE
      .  TEMP(NODE)=TEMP(NODE)+SDT*(DTEMP(NODE)+2.*TDI1(NODE)+2.*TDI2(NODE)
     1.  +TDI3(NODE))
      ...FIN

-------------------------------------------

      TO CALL-TDOT-FOR-FIRST-LEVEL
      .  CALL TDOT(TI1,TDI1)
      ...FIN

-------------------------------------------

      TO CALL-TDOT-FOR-SECOND-LEVEL
      .  CALL TDOT(TI2,TDI2)
```

```
00342        ...FIN

        ----------------------------------------

00343        TO CALL-TDOT-FOR-THIRD-LEVEL
00344        .  CALL TDOT(TI3,IDI3)
00345        ...FIN
00346        END

        ----------------------------------------

             PROCEDURE CROSS-REFERENCE TABLE

        00337 CALL-TDOT-FOR-FIRST-LEVEL
              00313

        00340 CALL-TDOT-FOR-SECOND-LEVEL
              00315

        00343 CALL-TDOT-FOR-THIRD-LEVEL
              00317

        00324 COMPUTE-FIRST-LEVEL-INTEGRAL
              00312

        00320 COMPUTE-HDT-SDT
              00311

        00333 COMPUTE-NEW-VALUE
              00318

        00327 COMPUTE-SECOND-LEVEL-INTEGRAL
              00314

        00330 COMPUTE-THIRD-LEVEL-INTEGRAL
              00316

        (FLECS VERSION 22.51)
```

```
---- RUN PARAMETERS ----

     TIME STEP 300. SEC.
     DISTANCE BETWEEN THE NODES   1.00 IN.
     RADIUS OF THE LOG    6 IN.
     THERE ARE  7 NODES.
     TIME OUT   864000. SEC.
     RESULT PRINT FREQUENCY  5


THE SIMULATION TERMINATED WHEN:

THE TEMPERATURE  2 INCHES FROM CENTER WAS AT LEAST 140.00 DEGREES F
THE MEDIUM TEMPERATURE WAS  180.00 DEGREES F
THE INITIAL LOG TEMPERATURE WAS   40.00 DEGREES F
TIME IN HRS   9.667
TEMPERATURE AT CENTER  138.70
TEMPERATURE  2 INCHES FROM CENTER  140.31 DEGREES F
TEMPERATURE   1.00 INCH BELOW THE SURFACE  170.99 DEGREES F
```

-----TIME AND TEMPERATURE-----

TIME (HRS.)	CENTER (F)	NODES 1.00 INCHES APART (F)					
0.000	40.00	40.00	40.00	40.00	40.00	40.00	40.00
.500	39.97	40.00	40.09	41.43	52.02	95.21	180.00
1.000	39.81	40.37	42.07	43.33	71.56	117.84	180.00
1.500	40.78	42.37	47.16	60.11	87.24	130.17	180.00
2.000	44.03	46.60	54.32	70.90	99.27	138.12	180.00
2.500	49.45	52.69	62.44	80.82	108.73	143.80	180.00
3.000	56.37	59.98	70.81	89.74	116.41	148.14	180.00
3.500	64.10	67.84	79.64	97.73	122.82	151.62	180.00
4.000	72.12	75.83	86.94	104.91	128.31	154.51	180.00
4.500	80.09	83.66	94.39	111.40	133.08	156.97	180.00
5.000	87.79	91.18	101.35	117.28	137.30	159.10	180.00
5.500	95.09	98.27	107.81	122.63	141.06	160.99	180.00
6.000	101.95	104.91	113.79	127.50	144.45	162.67	180.00
6.500	108.33	111.07	119.30	131.94	147.51	164.17	180.00
7.000	114.24	116.77	124.36	136.00	150.29	165.54	180.00
7.500	119.70	122.03	129.02	139.71	152.81	166.77	180.00
8.000	124.72	126.86	133.29	143.11	155.12	167.90	180.00
8.500	129.34	131.31	137.21	146.22	157.22	168.93	180.00
9.000	133.58	135.39	140.80	149.06	159.14	169.86	180.00
9.500	137.47	139.13	144.09	151.67	160.90	170.72	180.00
9.567	138.70	140.31	145.13	152.48	161.45	170.99	180.00

```
---- RUN PARAMETERS ----

     TIME STEP 300. SEC.
     DISTANCE BETWEEN THE NODES   1.00 IN.
     RADIUS OF THE LOG    9 IN.
     THERE ARE 10 NODES.
     TIME CUT   864000. SEC.
     RESULT PRINT FREQUENCY  5


THE SIMULATION TERMINATED WHEN:

THE TEMPERATURE  2 INCHES FROM CENTER WAS AT LEAST 140.00 DEGREES F
THE MEDIUM TEMPERATURE WAS  180.00 DEGREES F
THE INITIAL LOG TEMPERATURE WAS   40.00 DEGREES F
TIME IN HRS  22.000
TEMPERATURE AT CENTER  139.46
TEMPERATURE  2 INCHES FROM CENTER  140.19 DEGREES F
TEMPERATURE   1.00 INCH BELOW THE SURFACE  174.19 DEGREES F
```

-----TIME AND TEMPERATURE-----

TIME (HRS.)	CENTER (F)	NODES 1.00 INCHES APART (F)								
0.000	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
.500	40.00	40.00	40.00	40.00	40.00	40.07	41.22	51.06	93.31	180.00
1.000	40.00	40.00	40.00	40.02	40.22	41.55	47.95	68.99	115.12	180.00
1.500	39.99	40.01	40.05	40.27	41.33	45.34	57.10	83.32	126.95	180.00
2.000	40.00	40.07	40.27	41.05	43.61	50.59	66.17	94.25	134.53	180.00
2.500	40.11	40.30	40.86	42.53	46.85	56.42	74.41	102.77	139.91	180.00
3.000	40.47	40.83	41.32	44.67	50.71	62.32	81.70	109.60	143.98	180.00
3.500	41.20	41.77	43.48	47.35	54.92	68.03	88.13	115.23	147.20	180.00
4.000	42.37	43.16	45.53	50.45	59.28	73.44	93.81	119.97	149.84	180.00
4.500	44.02	45.02	47.99	53.84	63.66	78.52	98.86	124.02	152.05	180.00
5.000	46.11	47.29	50.81	57.41	67.99	83.27	103.39	127.56	153.94	180.00
5.500	48.60	49.92	53.89	61.11	72.22	87.70	107.48	130.67	155.58	180.00
6.000	51.41	52.86	57.19	64.85	76.32	91.85	111.19	133.44	157.03	180.00
6.500	54.49	56.02	60.63	68.62	80.29	95.74	114.59	135.93	158.32	180.00
7.000	57.76	59.36	64.16	72.36	84.12	99.39	117.71	138.19	159.47	180.00
7.500	61.18	62.82	67.75	76.06	87.81	102.82	120.60	140.25	160.52	180.00
8.000	64.69	66.36	71.35	79.71	91.36	106.07	123.29	142.15	161.48	180.00
8.500	68.25	69.93	74.95	83.27	94.77	109.14	125.80	143.90	162.37	180.00
9.000	71.84	73.51	78.51	86.75	98.05	112.04	128.15	145.53	163.18	180.00
9.500	75.41	77.06	82.02	90.14	101.20	114.81	130.36	147.06	163.94	180.00
10.000	78.95	80.58	85.46	93.44	104.23	117.43	132.44	148.48	164.65	180.00
10.500	82.44	84.04	88.84	96.64	107.15	119.94	134.41	149.82	165.31	180.00
11.000	85.87	87.44	92.12	99.73	109.95	122.33	136.28	151.09	165.94	180.00
11.500	89.23	90.75	95.33	102.73	112.64	124.61	138.06	152.28	166.53	180.00
12.000	92.50	93.98	98.43	105.63	115.23	126.79	139.74	153.42	167.08	180.00
12.500	95.68	97.13	101.45	108.43	117.72	128.88	141.35	154.50	167.61	180.00
13.000	98.78	100.18	104.37	111.13	120.11	130.88	142.89	155.52	168.11	180.00
13.500	101.78	103.13	107.20	113.73	122.41	132.79	144.35	156.50	168.59	180.00
14.000	104.69	106.00	109.93	116.25	124.62	134.63	145.76	157.43	169.05	180.00
14.500	107.50	108.77	112.57	118.67	126.75	136.39	147.10	158.33	169.48	180.00
15.000	110.22	111.44	115.11	121.00	128.79	138.08	148.38	159.18	169.90	180.00
15.500	112.85	114.03	117.57	123.25	130.75	139.70	149.62	159.99	170.30	180.00
16.000	115.38	116.52	119.94	125.41	132.64	141.26	150.80	160.77	170.68	180.00
16.500	117.83	118.92	122.22	127.49	134.46	142.75	151.93	161.52	171.04	180.00
17.000	120.18	121.24	124.42	129.50	136.21	144.19	153.02	162.24	171.39	180.00
17.500	122.46	123.48	126.53	131.43	137.89	145.57	154.06	162.93	171.72	180.00
18.000	124.65	125.63	128.57	133.29	139.50	146.89	155.06	163.59	172.04	180.00
18.500	126.75	127.70	130.54	135.07	141.06	148.17	156.02	164.23	172.35	180.00
19.000	128.78	129.69	132.42	136.79	142.55	149.39	156.95	164.83	172.65	180.00
19.500	130.74	131.61	134.24	138.45	143.99	150.57	157.84	165.42	172.93	180.00
20.000	132.62	133.46	135.99	140.04	145.37	151.70	158.69	165.98	173.20	180.00
20.500	134.43	135.24	137.69	141.57	146.70	152.79	159.51	166.52	173.47	180.00
21.000	136.17	136.95	139.30	143.04	147.98	153.83	160.30	167.04	173.72	180.00
21.500	137.85	138.60	140.85	144.46	149.20	154.84	161.05	167.54	173.96	180.00
22.000	139.46	140.19	142.35	145.82	150.39	155.80	161.78	168.02	174.19	180.00