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Title: Statistical Design and Analysis of Sonic Wave Pressure Treatment of Wood

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Literature reports have indicated that application of sonic pressure waves enhances the rate of impregnation of preservatives in wood. However, these studies have been limited and inconclusive. The technique or process is not in commercial use. In this study a laboratory scale treating cylinder connected to a mechanical sonic wave generator was used to measure the rate of impregnation of water in ponderosa pine at pressures of 0.28, 0.55 and 0.69 MPa and Douglas-fir at pressures of 0.55 and 0.69 MPa at a frequency of 30 Hz. Results were compared with those obtained at the same conditions of static hydraulic pressure. Statistical analysis showed that sonic treatments were at least as effective as, but not consistently superior to, hydraulic pressure treatments in the case of ponderosa pine. Statistical analysis of the results from Douglas-fir treatment showed that sonic treatment was superior than hydraulic treatment.

Statistical Design and Analysis of Sonic Wave Pressure Treatment of Wood

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CHAPTER 1
INTRODUCTION

1.1 Background

Wood is a renewable natural resource, which is available in large quantities at relatively low costs. It is still one of the major industrial building materials in many countries around the world. The low cost and availability of wood in various forms and sizes, together with such properties as relatively high strength with respect to weight, ease of shaping and fastening and low conductivity, have made it an outstanding building material. In the United States, wood is widely used in building construction, utility poles, railroad ties, marine piling, bridge structures, pulp and paper, plywood and fuel. Most of these applications require a long service life. Service life can vary considerably with the species of wood and the environment in which it is used.

Wood loses its mechanical strength and physical appearance due to mechanical damage and /or attack by decay agents, insects, and marine borers (Zabel and Morrell, 1992). The primary objective of preservative treatment of wood is to increase the life of the material in service, thus decreasing the ultimate cost of the product and avoiding the need for frequent replacements.

Many methods are used to treat wood. Of them, pressure treatment gives the best results because the preservative can be effectively placed deep into the wood at retentions which are sufficient to protect the material for long periods.

1.2 Problem Statement

Flow of any fluid through wood is governed by the anatomical features of the wood and the physical and chemical properties of the wood and the fluid. The flow paths vary depending on the type of wood and its condition, moisture content and a host of other parameters. In softwoods, tracheids, parenchyma cells, ray tracheids, resin canals and epithelial cells are the main flow paths. Hardwoods allow flow through vessels, gum canals, and, to a lesser extent, fibers. All these cells have pits which connect adjacent cells. The size and number of pits vary with species. Also as the sapwood turns to heartwood, the pits become aspirated, thereby blocking the flow paths. Similarly, formation of tyloses in heartwood considerably reduces the permeability of many hardwoods.

Generally, timber is classified as very permeable, permeable and resistant depending on the ease with which it can be impregnated with preservatives by normal pressure cycles. Permeability can be defined as that property of a porous material which characterizes the ease with which a fluid may be made to flow through it by an applied pressure, i.e. the permeability is the fluid conductivity of the material (Bailey, 1965). This concept can be described by Darcy's law using the following equation:

$$K = (Q \cdot L \cdot U) / (DP \cdot A)$$ where

K = permeability constant, cm^3 (liquid)/cm atm sec

Q = flow rate (milliliter per second)

L = length of porous media, cm

U = viscosity of flowing liquid(poise)

DP = pressure drop across porous media, atm

A = cross-sectional area of porous media, cm^2

The value of K, is determined by the structure of the porous material, but not by the porosity (void volume / total volume). Since the internal structure of wood is highly variable, permeability varies over a wide range.

Another major factor that affects fluid flow is the surface tension present at the air-liquid interface. Due to the micro-porous nature of the wood cell flow paths, these forces play a major role in fluid penetration. These relatively high forces must be overcome during pressure treatment.

In 1839, Bethel patented a pressure treatment procedure called the full cell process. In this method, wood is kept inside a cylinder and a vacuum is applied for a certain time to remove air from the wood. Then preservative medium is allowed to fill the cylinder and a high pressure of the order of 0.48 - 1.38 MPa is applied to the wood. With this method, the preservative penetrates the cell walls and lumens.

The empty cell processes are alternative procedures for treating wood to lower retentions. The Rueping and Lowry processes are empty cell processes which do not employ the initial vacuum. Therefore, air inside the wood becomes compressed during the pressure cycle. The air expands as the pressure is released and kicks back excess preservative from the wood. This treatment is used especially with oilborne preservatives to reduce costs by kicking out the excess oil from the wood. There are other processes like the Cellon process, which are not widely used in the U.S.

It is interesting to note that the full cell process is still the major process used in preservative treatments with waterborne preservatives. Various alternative treatment techniques have been proposed to improve treatment and reduce environmental problems including sonic treatment. There were some earlier reports of wood treatment using pulsating pressure; however, none of these studies tried to systematically compare the conventional treatment procedures with the sonic treatment. In all cases the pressure developed by the sonic waves was not measured. The lack of systematic study of sonic pressure treatment process encouraged this investigation.

1.3 Research Objectives

This study focused on sonic treatment of ponderosa pine sapwood; which is an easily treatable species, and Douglas-fir heartwood, which is very difficult to treat. Sonic waves at 30 Hz were applied to ponderosa pine samples at pressures of 0.28, 0.55 and 0.69 MPa and Douglas-fir samples at 0.55 and 0.69 MPa pressure. The objectives of this study were: a) to design and fabricate a sonic generator for pressure treatment b) to compare the absorption rate at various pressures of the two species for sonic and hydrostatic treatment conditions, and c) to propose guidelines for future research in this area.

1.4 Research Methodology

Wood samples were treated with sonic pressure waves at different pressure conditions. The absorption of water during treatment was compared to that obtained from hydrostatic pressure treatment on a matched sample. This comparison indicated which treatments produced better absorption in the samples. In order to conduct statistical analysis, a control group where both samples were treated with hydraulic pressure was also generated. A paired comparison technique was used to compare the sonic and hydraulic treatments.

1.5 Definitions

Sonic treatment means that wood is treated with an oscillating pressure wave. Pressure oscillates between a low and a high value, at a particular frequency, 30 Hz in this case. The wave shape is almost like a sine wave but with a depression at the high pressure side. The pressure in the cylinder is indicated by the Root Mean square pressure.

Hydaulic treatment applies a static pressure on the treating medium, which in this case is water. This pressure is applied by using house air on top of a water column connected to the treating cylinder.

The *sonic generator* is capable of producing oscillating pressure waves.

Absorption means the quantity of preservative solution (water in this case) retained by the wood (kg of water per m^3 of wood).

1.6 Thesis Organization

This report is organized in five chapters. Chapter 1 has sections on introduction, problem statement, research objectives and research methodology.

Chapter 2 reviews the literature that has been published on the theoretical aspects and anatomical features of wood treatment. Also previous studies conducted in the sonic pressure treatment are discussed.

Chapter 3 describes the experimental equipment and test procedures. This chapter includes details of each of the pieces of equipment used in the process. This is followed by description of sample preparation, initial equipment set up, and the actual test procedure. Following this, the experimental design for this study is explained.

In Chapter 4, the data for ponderosa pine and Douglas-fir are summarized. Also the statistical analysis and discussion are included in this chapter.

Chapter 5 includes the conclusions and also covers possible areas of future research.

CHAPTER 2
LITERATURE REVIEW

2.1 Study on theoretical aspects

A large number of studies have been performed on preservative treatments of wood and factors influencing these treatments (Nicholas, 1973). Similarly a number of studies have investigated the steady-state flow of fluids through wood (Siau, 1971).

Kelso *et al* (1963) made a comprehensive study on fluid conductivity of wood as a porous medium. They concluded that air blockage commonly produced a disproportionality of flow and this was probably caused by air bubbles remaining in the wood. If a gas bubble is forced to flow through fine capillaries filled with liquid, the bubble will not pass through the constriction unless a certain force is exerted on it. Distortion of the bubble to drive it from a large area through a small tube would involve increased surface energy at the interface between the gas and the liquid at the entrance of the tube. Thus, the bubble would transmit less energy than it received. This incomplete transmittal of energy by a gas bubble through a liquid-filled capillary is called the Jamin effect. Application of slight external pressure drives the bubble partially into the constriction to a position where the distortional surface tension forces are in equilibrium with the externally applied pressure. Such a system behaves as if the capillary contains an obstruction with little or no flow possible until the bubble is driven out. The authors obtained several results supporting the validity of the Jamin effect. They also observed that a mechanical shock can cause liquid to cavitate, greatly reducing the permeability.

In order to drive an air bubble through a pit opening, the water-air interface must be deformed to a hemispherical shape where the radius of the meniscus becomes equal to the radius of pit opening, provided the contact angle is zero. The pressure differential required to move the air bubble may be calculated as P0 - P1 = 21.4/R, if the contact angle is assumed to be zero and surface tension of water is 72.75 dyne/cm at 200^{o}C; where P0-P1 is the pressure differential and R is the radius of the capillary. From this equation it can be seen that a pressure of approximately 1.48 MPa is required to force a water-air interface through a capillary of 0.1 micro metre radius, which is a typical value of pit opening. Similar forces are expected to promote aspiration of pits, where air on one side of the pit membrane which is unable to pass through the pores pushes the membrane to the other side until the torus block the pit border.

Sucoff *et al* (1965) studied the permeability of unseasoned xylem of northern white cedar to test the applicability of Darcy's law. They found disproportionalities between the rate of flow and the pressure drop. They opined that turbulence and non-linear laminar flow which are described with a quadratic term would better explain this deviation.

Similarly deviations have been observed where an increase in pressure drop is seen with an increase in specimen length. Bramhall (1975) conducted experiments on Douglas-fir heartwood and attributed the results to pit aspirations in heartwood. Pit aspiration in heartwood considerably reduces the flow of liquid between adjacent tracheids. Also, alternate paths are blocked so that a tracheid series will not conduct fluid beyond restriction. This results in decreasing numbers of conducting tracheids with increasing depth of penetration. He suggested a modification to Darcy's law by introducing an exponential term which explained this phenomenon.

Ronze *et al* (1988) suggested a model consisting of a series of elements in which flow takes place, each element including a stagnant zone. They also suggested that there was a partial recycling of fluid from the final to initial element. They opined that the volume fraction occupied by the stagnant zone increased sharply with the length of sample and this variation probably explained the increased pressure drop as length of the sample increased.

Bolton *et al* (1988) re-examined some deviations from Darcy's law and suggested a model, which also considered transverse flow. They argued that there could be some transverse flow in heartwood because all pits may not be aspirated. They concluded that impermeable softwoods should not necessarily be expected to deviate from Darcy's law, even though some of them followed Bramhall's model.

2.2 Anatomical features related to flow of liquids through wood

Wood is a material with extreme variability. Wood consists of sapwood and heartwood. Sapwood contains live cells and allows fluid movement through them. The sapwood dies and is converted into heartwood after some years. Hardwoods contain vessels, tracheids, fibers, parenchyma cells and epithelial cells. Vessels are larger in diameter than the other cells and conduct a large amount of fluid in the longitudinal direction. Tracheids also conduct fluid, although they are smaller in diameter. Parenchyma cells store starch and other materials. Epithelial cells surround the gum canals.

Softwoods contain tracheids, parenchyma cells, ray tracheids, resin canals and epithelial cells. Tracheids are the most important cells in terms of fluid flow movement. Ray tracheids allow transverse flow of fluids within the wood. Epithelial and parenchyma cells have similar functions as in hardwoods. Resin canals carry resins in the axial direction. Tracheids, vessels, rays and parenchyma cells which are the main cells responsible for fluid movement, have pits in them. A pit is defined as a recess in the secondary wall of a cell , open to a lumen on one side and including the membrane closing the recess on the other side. Normally two complementary pits in adjacent cells make a pit pair. There are three kinds of pits; bordered, semi-bordered and simple. Bordered pits are the most common type present between tracheids in softwoods. Coniferous bordered pits have a membrane with a margo and a torus, whereas hardwood bordered pits have no torus.

Wardrop and Davies (1961) investigated the morphological factors related to the penetration of liquids into wood. In sapwood of hardwood, the penetration path was through the vessels and thereafter via the pits to adjacent tracheids, vertical parenchyma and ray cells. The flow continued from the rays through pits to tracheids and vessels that were in contact with those rays. The penetration path in heartwood was similar to that in sapwood except that some of the vessels were blocked with tyloses. Vertical and radial parenchyma cells allowed fluid flow more easily due to thin walls and simple or semi bordered pits. In softwoods, initial flow occurs through tracheids to adjacent tracheids through the pits and spreads laterally through the ray cells. Resin canals also allow initial entry of fluid into wood. Ray parenchyma cells showed better conductivity than ray tracheids. The thin walls of parenchyma cells and numerous pits present in them account for the better conductivity. The main resistance to the initial flow of liquids into sapwood is governed by the pit membranes. Since the pit membrane in softwood consists of a series of radially arranged microfibril bundles, particle suspensions can pass through this material. In hardwoods, the pit membrane is a complex structure consisting of two adjacent primary walls and the inter-cellular substance and hence particle suspensions do not move well through this material. Resistance to passage of liquids in heartwood is increased due to the formation of tyloses in vessels and encrustation of pits in the case of hardwoods and due to increased aspiration of pits and encrustation of the torus and pit membrane in the case of softwoods.

Buckman *et al* (1933) studied certain factors influencing the movement of liquids in wood. They concluded that maximum and average effective diameters of pores in pit membranes varied with moisture content. Below the fiber saturation point, the flow rate decreased with increased moisture content, which the authors did not predict the flow rate above the fiber saturation point.

The influence of pressure upon the flow of water through wood was found to be a characteristic of the wood species. Many species showed decreases in flow rates with respect to time. They observed that rate of flow of organic and aqueous salt solutions could not necessarily be predicted by the viscosity of these fluids.

Bolton *et al* (1987) investigated the role of inter-vessel pits and vessel plugs in sycamore to determine flow path ways through and between vessels. Interestingly, they found that inter-vessel pit membranes were absent in this species; however, pit membranes between vessel-ray parenchyma and vessel-fiber interfaces were intact. The membranes only rarely had pores in them.

Bailey (1965) conducted an extensive study on the permeability of wood and observed that if wood is gradually conditioned to high pressures, increased flow rates are obtained, but if it is immediately subjected to high pressures, it reacts in a quite different way. Also, when the direction of flow was reversed, slightly more flow than originally noted was observed. The author suggested capillary swelling as a possible explanation for this effect. Regarding air blockages, the author opined that although entrapped air and resistance due to surface tension effects by air-liquid menisci are important in initial penetration, once the flow is established it seems likely that any air present will exist in discrete isolated pockets and will not affect subsequent flow. He also suggested that at some critical vacuum pressure, which probably varies from species to species, additional flow paths are created possibly due to some kind of membrane rupture. Further, a study was conducted on Douglas-fir bordered pits which are primarily present on the radial walls of the earlywood tracheids. They are also present on the tangential walls, but only on the edge of the growth rings. Thus, for fluids moving radially, the ray cell network in parenchyma cells would seem to provide the most obvious flow channels, while pits are ideally positioned for tangential flow. The author found that the ratio of radial to tangential flow was of the order of 10:1. Ends of parenchyma cells were found to be impermeable. It was observed that relatively scarce ray tracheids and resin canals provided the best pathways for liquid movement. Similarly, the author observed that the ray-vertical tracheid pit membrane for Douglas-fir was impermeable. Also, longitudinal permeability in earlywood was much greater than that in latewood, because of the larger diameter of tracheids in earlywood and abundance of bordered pits on their walls.

2.3 Sonic treatments in the past

An oscillating pressure method (OPM) of preservative impregnation of wood that is resistant to treatment by usual pressure processes was described by Hudson and Henriksson (1956). This process utilized a rapid cycling of pressure and vacuum to obtain penetration of aqueous salt solutions into unseasoned wood. OPM treatment was in commercial use from 1951 and the retention of treatment solution was more than that of the conventional full cell method.

Pilot plant evaluation of shock-wave pressure treatment by Burdell and Barnett (1969) revealed that shock waves acted as an effective means for accelerating the injection of liquid preservatives. In different species and processes, the shock waves showed improvements in different aspects, for example reducing steaming cycle time with southern yellow pine poles and reducing time required per charge for oak crossties. No degradation in the physical properties was noted in wood treated by shock waves and the authors indicated that the pilot plant could be scaled to commercial applications. The internal cylinder pressure was not measured during these experiments. Thus, their evaluation of the effectiveness of the method was limited.

Borgin *et al* (1970) studied the capillary penetration of liquids into wood by use of supersonic waves. They investigated the effect of supersonic waves on the capillary penetration of different kinds of non-polar compounds like paraffin and aromatic hydrocarbons. They conducted experiments at room temperature and pressure on *Pinus radiata* by treating with a supersonic generator which produced about 500 Watt available sound energy at a frequency of 40 kHz. They observed that absorption of non-polar compounds was not improved by supersonic waves. When they added a hydrophilic group into the straight hydrocarbon chain, supersonic waves increased the absorption. Water, even though hydrophilic, showed a negative effect with supersonic waves. But supersonic waves increased absorption when surface tension of water was lowered by using surface active agents.

The effect of surfactants and ultrasonic energy on the treatment of wood with chromated copper arsenate(CCA) was studied by Walters (1977). In a study with ponderosa pine and CCA, he concluded that neither ultrasonic energy, nor its interaction with presoaking time had any significant effect on the absorption of chemical by wood. Surfactants generally increased absorption, even though the effect was different for different processes.

Avramidis (1988) conducted experiments on the effect of ultrasonic energy on the absorption of preservatives by wood. The absorption of CCA by spruce, Douglas-fir and ponderosa pine and other preservatives by ponderosa pine were investigated at atmospheric pressure and 200°C. Ultrasound increased uptake for all species and preservatives with the effect being more predominant in more permeable species.

2.4 Prospects of sonic wood treatment

Various investigations cited in the previous sections encouraged further investigation into the effect of sonic waves to treat wood. Oscillating pressure treatment enhanced the rate of uptake of preservatives. Air blockages are suggested to be one of the main reasons for decreased fluid penetration in wood. The effect pressumably relates to the resistance offered by the air-preservative interface due to surface tension forces. Similarly, pit aspiration is of great concern with respect to fluid movement in heartwood of softwood species. Sonic pressure waves may overcome these difficulties. In each sonic pressure cycle, an instantaneous high pressure pulse can be driven through the treating medium, which applies a very high instantaneous force that may help to overcome the surface tension forces offered at the micro pores and may drive the air out of cells allowing treating medium to flow through the cells. Similarly, the oscillating pressure waves may open aspirated pits. If we can find the natural frequency at which pit membranes can be vibrated, a sonic pressure wave applied at this frequency may vibrate the pit membranes; thus keeping them open. Cavitation effects suggested by Kelso et al (1963) causes concern since the high pressure gradient induced in each cycle may impart turbulent flow. This may lead to cavitation of preservative medium inside the cells, producing bubbles. Here again the high pressure pulses themselves may drive these bubbles out of the cavities. The aspects considered above suggest that flow of liquids through wood can be influenced by application of sonic waves.

CHAPTER 3
EXPERIMENTAL SET UP AND TEST PROCEDURES

3.1 Introduction

The schematic of the test set up is shown in Figure 3.1. The basic procedure followed here was to compare the rate of absorption with sonic waves to the rate of absorption using hydraulic (static) pressure under various conditions.

3.2 Equipment

3.2.1 Treatment cylinder

A carbon steel cylinder 10 cm in diameter and 30 cm long was fabricated from a 10 cm carbon steel pipe. One end of the cylinder was welded to a circular plate of same diameter. A 25 mm galvanized iron pipe, 16 cm long, was inserted to the hole in the middle of this plate and was socket welded to it. The other end of the pipe was threaded into a manually operated on-off ball valve, which was further connected to the diaphragm chamber of the sonic generator. Two 19 mm pipes were welded, one to the bottom of the cylinder near the welded end and the other on the top of the cylinder near the open end. Both pipes were connected to 19 mm on-off isolation valves. A 19 mm

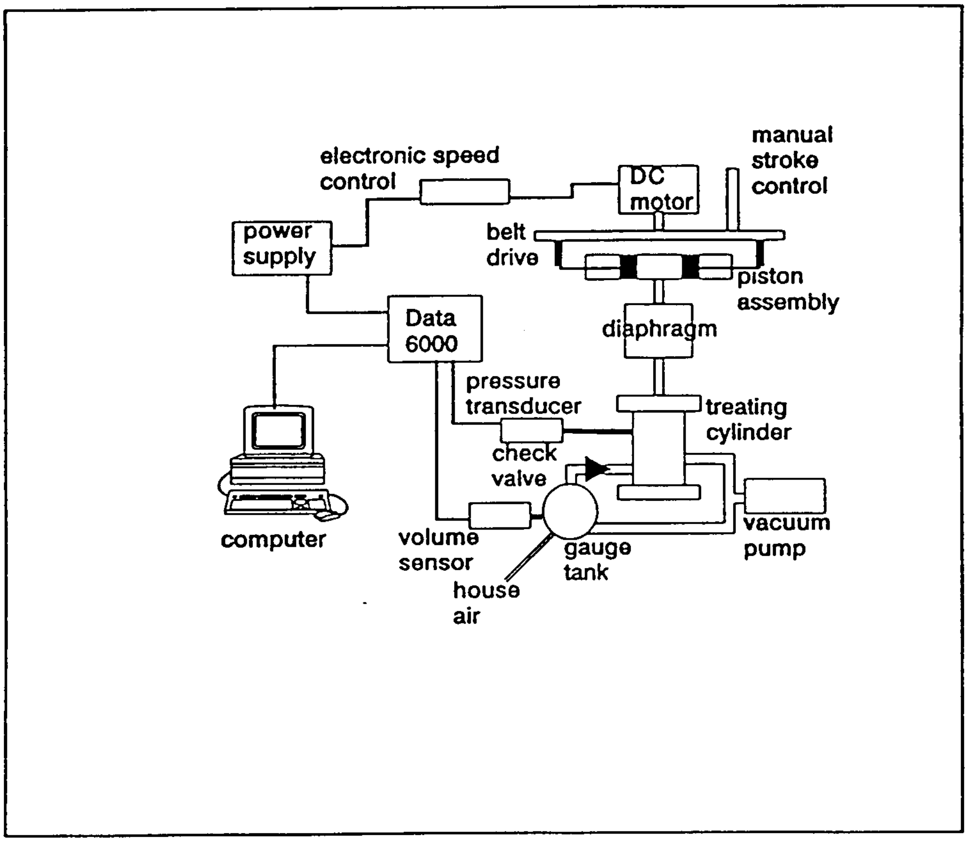

Fig.3.1 Schematic of the test setup for treating wood samples under sonic and hydraulic pressure conditions.

on-off isolation valve was standard for this experimental set up. The bottom tube was diverted into 2 pipes through a t-joint. Both these pipes had individual isolation valves on the other end. One of these on-off valves connected the cylinder to the check valve through another isolation valve. The check valve was connected to a gauge tank through an isolation valve which allowed flow only in one direction, i.e. from the gauge tank to the cylinder. The bottom pipe was also connected to a reservoir through another isolation valve. The other diversion from the bottom tube was connected to the pressure transducer, again through an isolation valve. The top tube was connected to a clear PVC tube(19 mm, diameter) which was used to observe the water level while filling the treatment cylinder. The other end of the PVC tube was connected to a vacuum pump through an isolation valve. The PVC tube also had an exhaust port, which again was opened to the atmosphere through an isolation valve. The exhaust port helped to release the vacuum, and to vent out pressurized air from the cylinder. The open end of the cylinder was closed by a lid, which was a circular plate, with the help of four bolts. A viton O-ring on the edge of the cylinder provided an air tight seal with the lid.

3.2.2 Gauge tank

The Gauge tank was a vertical clear PVC 5 cm diameter pipe, approximately 50 cm high. In the bottom, the tank was connected to the check valve and the reservoir through separate isolation valves. The top end was connected to the house air supply, and the vacuum pump and exhausts through individual isolation valves. A displacement sensor equipped with a float gauge (Temposonics linear displacement sensor) measured the volume change in the gauge tank to within +/- 0.22 ml.

3.2.3 Sonic generator

The treatment cylinder was connected to the sonic generator through a 25 mm diameter pipe containing an isolation valve. The sonic generator consisted of two hydraulic pistons (modified airplane engine pistons) with the piston heads facing each other. These pistons pumped oil against a rubber diaphragm (1 mm thickness and 10 cm diameter) and were connected to a DC electric motor by a timing belt assembly. The speed of the DC motor was varied by using variable resistance. The timing belt assembly was connected to a vertical screw drive stroke control mechanism, which allowed the operator to vary the amplitude of the sonic waves. When the stroke control mechanism was adjusted so that the pistons moved in exact opposition to one another, the amplitude of the wave produced was maximized. When the pistons are moving in concert, there was no pumping action to move the diaphragm and hence the sonic amplitude was minimized. This amplitude control was required to maintain a constant sonic pressure in the treatment cylinder, since the sound absorptivity of the system changed as the treatment progressed. The frequency generated was varied by controlling the speed of the driving motor. Since the speed of the motor was dependent on a changing load, an electronic feed back mechanism was installed to monitor the speed of the motor and alter the power input to maintain a constant rpm. The sonic wave generated in this manner was not a true sinusoidal wave (Figure 3.2).

3.2.4 Pressure transducer

The pressure transducer was an OMEGA model PX120-500GV, which had an operating pressure range of 0 to 3.45 MPa. The sensitivity was 10 mV/Volt and an accuracy of +/-1% of full scale. Reporting the pressure applied by the sonic wave was somewhat arbitrary, since it was time dependent. A root mean square(rms) value calculated by the data acquisition system was used to represent the pressure

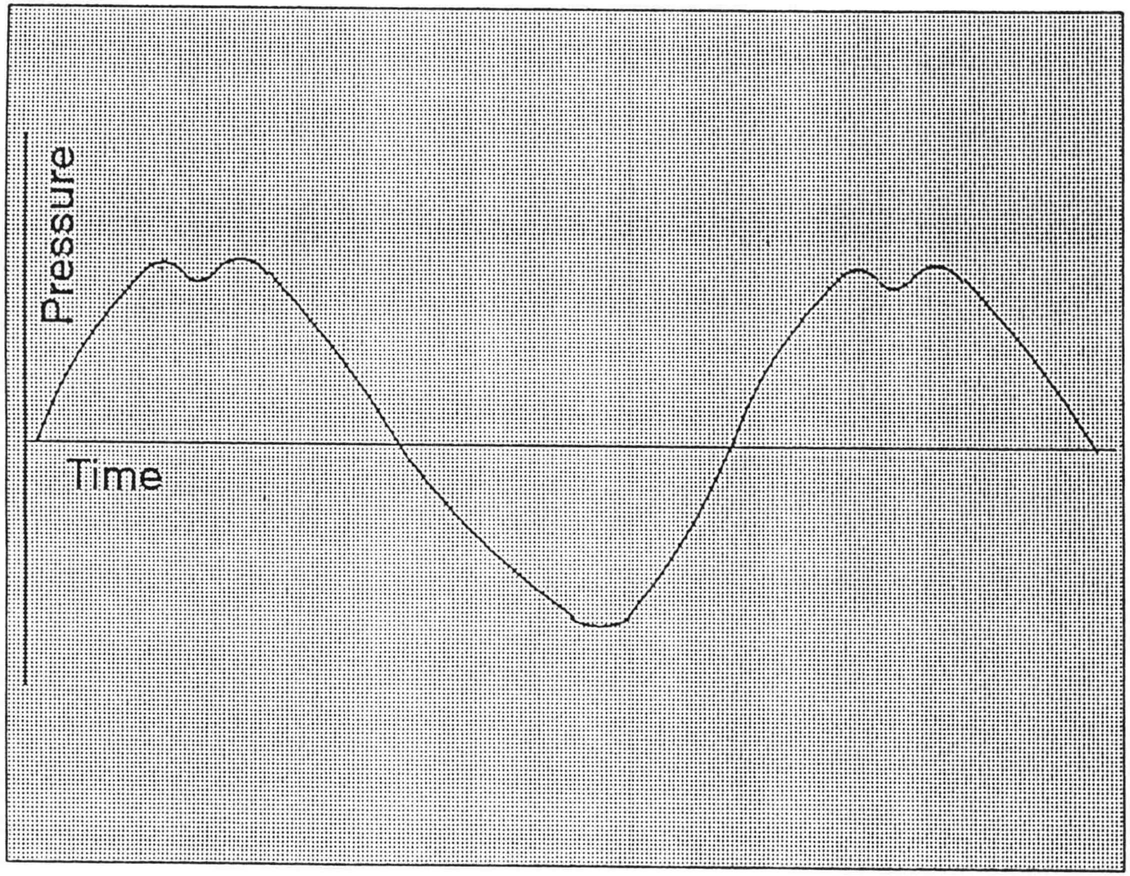

Fig.3.2 A typical sonic pressure wave form generated ay 30 Hz. by the sonic generator, which is applied to the treatment medium in the treatment cylinder.

in the system. The rms pressure reflects the power required to generate the wave and was the appropriate pressure to use in scale up calculations.

3.2.5 Data processor

The data acquisition system consisted of a DATA 6000, a high precision electronic module. It received the signals from the pressure transducer and the volume displacement sensor which were converted into pressure and volume measurements that were displayed on a screen and also recorded in a computer. A 'C program' helped to acquire data automatically. The DATA 6000 contained an oscilloscope to observe the shape of the sonic wave.

3.2.6 Vacuum pump

The vacuum pump was used to de-aerate the water, pull vacuum on the wood samples and also to fill the treatment cylinder and the gauge tank. A vacuum of 710 mm Hg could be attained by the model vacuum pump.

3.2.7 Samples

Wood samples were clear ponderosa pine (*Pinus ponderosa* Laws) sapwood and Douglas-fir [*Pseudotsuga* *menziesii* (Mirb.) Franco] heartwood, approximately 3.8 cm x 6.4 cm x 30 cm. They were prepared by sawing an approximately 30 cm long section from a randomly selected board (nominal 5 cm X 15 cm), then ripping the board down the center. This gave side matched sets of specimens which were labeled "A" and "B". These side matched samples were used for ponderosa pine tests. For Douglas-fir, end matched pieces were used as "A" and "B" instead of side matched pieces. The end matching enhanced uniformity between samples with respect to the number of rings per inch and the flow paths. The longitudinal ends were coated with epoxy resin to prevent end penetration. The samples were stored in an environmentally controlled room for a minimum of two weeks to achieve a final moisture content of 15%.

3.2.8 Sample preparation and numbering

Commercially available clear boards of nominal dimension 5 cm x 15 cm were selected. Generally these boards were 9 to 15 m long and were either air dried or kiln dried. These boards were sawn into the required sizes, properly identifying them with labels which allow the matching of the pieces and also to identify the origin of the sample with respect to the board. For the ponderosa pine tests, side matched pieces were used. The code used for numbering the samples was: PP42001A, PP42001B, etc. The first two letters (PP) stood for ponderosa pine. The first digit (4) which represented the test pressure (0.28 MPa or 40 psi) changed with pressure; 8 for 0.55 MPa (80 psi) and 1 for 0.69 MPa (100 psi). The second digit represented the type of test; whether it was a control (both samples treated with hydraulic pressure) group or a treatment (one sample treated by sonic and its pair by hydraulic pressure) group. The control group was indicated by the digit 0 and treatment group(sonic) by 2. The third and fourth digits represented the serial number of the board. The last letter , either A or B indicated the matched samples. All the A samples were used for sonic treatment and B samples for hydraulic treatment. In the control group, both A and B were tested under hydraulic pressure.

In the case of Douglas-fir, an improved coding was used to keep track of the board information to identify which board was used to make each sample. The coding used was as follows: D120101A, D120102A, etc. The first alphabet represented Douglas-fir. The first and second digits represented pressure and the type of treatment, respectively, as in the case of ponderosa pine. The third and fourth digits represented the serial number of the board. The fifth and sixth digits represented the serial number of the sample. The last alphabet identified side matched samples A and B. In this case since end-matched pieces were used as pairs, D120101A and the adjacent sample D120102A were used as a pair. The set of sample A's were used for the treatment group and B's for the control group.

The samples were end coated with 2 coats of water proof epoxy resin (Gluvit) to prevent end penetration. The samples were then stored in an environmentally controlled room for at least 2 weeks. Once uniform moisture content was attained, the samples were ready for testing.

3.3 Test Procedure

3.3.1 Initial equipment set up

The sonic generator also needed some preliminary adjustments. Initially, the generator was filled with oil ('Sta-lube', Hydraulic and Jack oil) and care was taken to eliminate any air bubbles entrapped in the generator. The screw drive was set to the zero stroke position and the pistons were set with zero phase angle. In this case, when the motor drove the generator, both pistons moved in the same direction and as a result no pressure was generated.

Water was de-aerated before by closing the treatment cylinder and opening the valve connecting the cylinder and vacuum pump. The vacuum pump was switched on and the inlet valve connecting the cylinder and the reservoir was opened to allow water to fill the cylinder. Once the cylinder was full, the inlet valve was closed and a 710 mm Hg vacuum was applied to the water for one half hour. The vacuum was released and the water was drained back into the reservoir. If the quantity of water in the reservoir was large, the process was repeated again. The de-aerated water was placed in the gauge tank using the vacuum pump.

The samples were removed from the environmentally controlled room just before testing and length, breadth, width, weight and identification number of the samples were recorded. A coin was tossed to determine the treatment, sonic or hydraulic, to ensure randomization.

The sample was placed in the treatment cylinder and vacuum was applied for three or 30 minutes for ponderosa pine or Douglas-fir, respectively, based on initial experiments. At the end of the vacuum period, the inlet valve was opened to allow the water to fill the tank. Vacuum was applied for another one minute, to extract any entrapped air bubbles, then released and the outlet valve of the treatment cylinder was closed. The valve connecting the gauge tank and the treatment cylinder was opened and pressure was slowly applied over 30 to 40 seconds until the required value was achieved and then held for the desired time.

To apply sonic pressure, the valve between the sonic generator and the treatment cylinder was opened before the test began. The DC motor was started and set to the speed required to give a 30 Hz sonic wave. The screw drive was slowly turned clockwise to increase the stroke from zero until the RMS pressure reached the required value (0.28 MPa, 0.55 MPa, etc.). Minor adjustments were required to stabilize the pressure and the frequency. Once these parameters stabilized, the screw drive was locked to maintain the same values throughout the test. Minor adjustments were some times required approximately twice per hour.

For the hydraulic treatment, the valve between the sonic generator and the treatment cylinder was closed. Air pressure was applied to the water column in the gauge tank from the house air supply after passing through a filter. The air filter knob was locked to maintain constant pressure throughout the test.

The test duration for ponderosa pine was 40 minutes and for Douglas-fir 120 minutes. Ponderosa pine was generally treated to refusal before 40 minutes, while Douglas-fir showed constant rate of absorption even after 120 minutes. However, the tests were concluded after 120 minutes due to concerns about possible overheating of the sonic generator. Once the required time was reached, the pressure was released, the data acquisition was stopped and the sample was taken out and re-weighed. The sonic and hydraulic tests were done alternatively.

3.4 Statistical Design

3.4.1 Identification of variables

The initial objective of these tests was to identify all the variables involved in sonic treatment. Once all the variables were identified, 3 or 4 variables could be chosen for study. The two treatments were identified as sonic and hydraulic treatment. The most important variables were pressure level (0.28, 0.55 and 0.69 MPa), frequency of sonic waves (low frequency and high frequency), wood species (easily treatable and difficult to treat), type of preservative (waterborne and oilborne, which have different viscosities and surface tensions), shape of the sonic wave (sine, modified sine, sawtooth), temperature (cold and hot), and evacuation time (few minutes to hours). A careful study of the literature and the limitations of the sonic generator narrowed down the variables to treatment type, pressure condition and the wood species.

3.4.2 Test parameters

The various test parameters were selected for this study as indicated in table 3.1.

Table 3.1 Test parameters

Pressure (MPa)	Species	Frequency (Hz)
0.28	ponderosa pine	30
0.55	ponderosa pine	30
0.69	ponderosa pine	30
0.55	Douglas-fir	30
0.69	Douglas-fir	30

In ponderosa pine initially 0.28 MPa tests were conducted and were extended to higher pressures 0.55 and 0.69 MPa. In Douglas-fir, tests were limited to 0.55 and 0.69 MPa since absorption was very low at 0.28 MPa and was of less interest for industrial applications. In all these cases, frequency was kept at 30 Hz because the sonic generator was designed for that frequency.

3.4.3 Statistical assumptions and analysis procedures

The previous studies did not have information about the variance of the absorption values in samples made from any particular species. In order to fix the number of replicates required for each run, a preliminary trial was conducted. The standard deviations on absorption values were approximately 50 kg/m^3 for both sonic and hydraulic tests. Therefore it was assumed that population standard deviation for both the tests were the same as 50 kg/m^3. It was also assumed that the population was normal. With these basic assumptions, the number of samples were calculated for a mean difference ($\mu1-\mu2$) of 100 kg/m^3 between sonic and hydraulic tests. The procedure given by Montgomery (1991) was used to determine the number of samples. The choice of sample size and the probability of type II error β are closely connected. A graph (operating characterisic curves) of β versus δ, which was the true difference in means for a particular sample size, is given in Montgomery (1991). This graph was used to test the null hypothesis of equal means, μ (with population standard deviation, σ, assumed to be equal to 50 kg/m^3), at a level of significance $\alpha = 0.05$ and type II error, $\beta = 0.05$. The parameter on the horizontal axis of the graph was calculated as

$$d = \frac{|\mu1-\mu2|}{2\sigma}$$

and the sample size used to construct the curves, n^*, was obtained from the curves. From n^*, prescribed sample size

(n) of 9 per test run was calculated . For simplicity, the sample size was raised to 10.

The assmption of normality of the sample sets were investigated by conducting tests described by D'Agostino(1990), by using NCCS (Number Crunching Statistical System, a statistical package). If the probability level was less than 0.05, the normality hypothesis was rejected. All data sets computed probability values higher than 0.05 except ponderosa pine control group 'A' samples at 0.69 MPa and Douglas-fir samples which under went sonic treatment at 0.55 MPa. Since the deviation from normality was observed only in two cases and t-tests were robust to deviations from normality, it was decided to perform paired t-analysis on the data. The deviations from normality assumption might have affected results in the two specific cases mentioned above.

Since matched samples were used, it could not be assumed that observations from different groups were drawn independently. Therefore a paired t-statistic, which is the proper tool for drawing inferences when observations are paired, was developed. To perform paired t-analysis, the treatment(group) difference was calculated for each pair. A set of differences constitutes a random sample from a single population of such differences. When there is no difference in the original groups, the population of differences will be centered at zero. So this analysis estimates the mean difference with particular attention to the possibility that the mean difference might be zero.

A hypothesis testing was suggested as follows.

H0 = μ equal to zero

H1 = μ not equal to zero

where μ is the mean of the differences for each pair.

The t-statistic was calculated as per the following formula.

$$\text{t-statistic} = \frac{(\text{estimate} - \text{parameter})}{\text{SE(estimate)}}$$

where estimate	=	the mean of difference in absorption in each pair
parameter	=	zero
SE(estimate)	=	standard error of the estimate

The 2-sided p values corresponding to the t-statistic were obtained from the t-tables for 90% confidence levels. The null hypothesis was rejected if the 2-sided p value was less than 0.1, which meant that there was a significant difference between the two treatments applied to the pair.

CHAPTER 4
DATA ANALYSIS AND RESULTS

4.1 Data Summary

The data includes sample number, weight of the sample before test (Dry wt.(kg)), weight of the sample after test (Wet wt.(kg)), volume of sample (Volume(m^3)), absorption by weight which is the value obtained by dividing the difference in wet and dry weights by the volume of sample (Abs. wt.(kg/m^3)), absorption by volume which is the value obtained by dividing the volumetric change of water recorded by the gauge tank, by the volume of sample (Abs. vol.(kg/m^3)), percentage difference in absorption by weight and volume (diff. %), time at which volume data from gauge tank was recorded, and the absorption calculated from the volumetric change by the gauge tank at these time intervals (kg/m^3). There were differences in the absorption by weight and absorption by volume in all cases. This deviation probably reflects inability to accurately measure absorption during the one minute required to fill the vessel.

4.1.1 Ponderosa pine data

Treatment and control groups were made for ponderosa pine sapwood samples at 0.28, 0.55 and 0.69 MPa and the data was included in Appendix 1. Plots of typical absorption patterns given by the sonic and hydraulic treatments for the 0.55 MPa treatment group were prepared(Figure 4.1), as were the graphs of average absorption of the 10 samples at time intervals 2.5 minutes, 5.5 minutes, 10 minutes, 16 minutes and 20 minutes (Figures 4.2 and 4.3).

The volumetric change in the gauge tank was measured in terms of volts. These readings were converted into absorption by volume by using the following formula.

Abs. vol. = $(R_t - R_o) \cdot k / V$, where

R_t = Reading at any instant of time t, volt

R_o = Reading at time zero, volt

k = factor (0.155 kg/volt)

V = Volume of sample, m^3

4.1.2 Douglas-fir data

Treatment and control groups were made for Douglas-fir heartwood samples at pressures 0.55 and 0.69 MPa and the data is included in Appendix 2. Plots were prepared comparing absorption in sonic and hydraulic treatments (Figure 4.4) as well as treatment time Vs absorption (Figures 4.5 and 4.6).

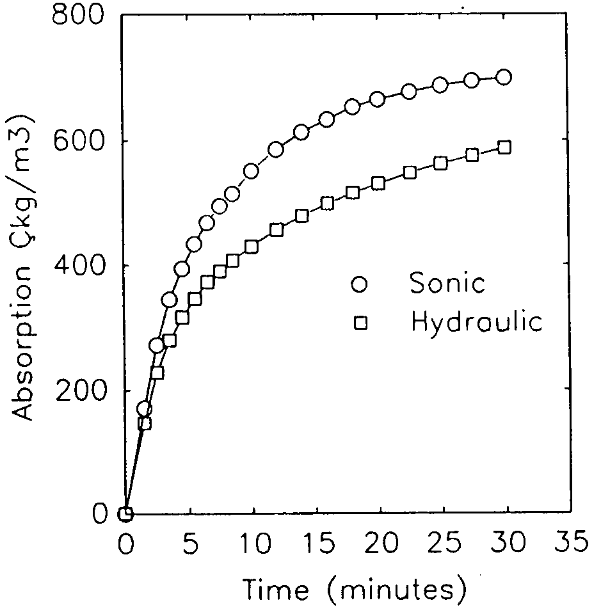

Fig.4.1 Absorption curves obtained from sonic pressure applied to ponderosa pine sample A and hydraulic pressure applied to the matched sample B, at 0.55 MPa

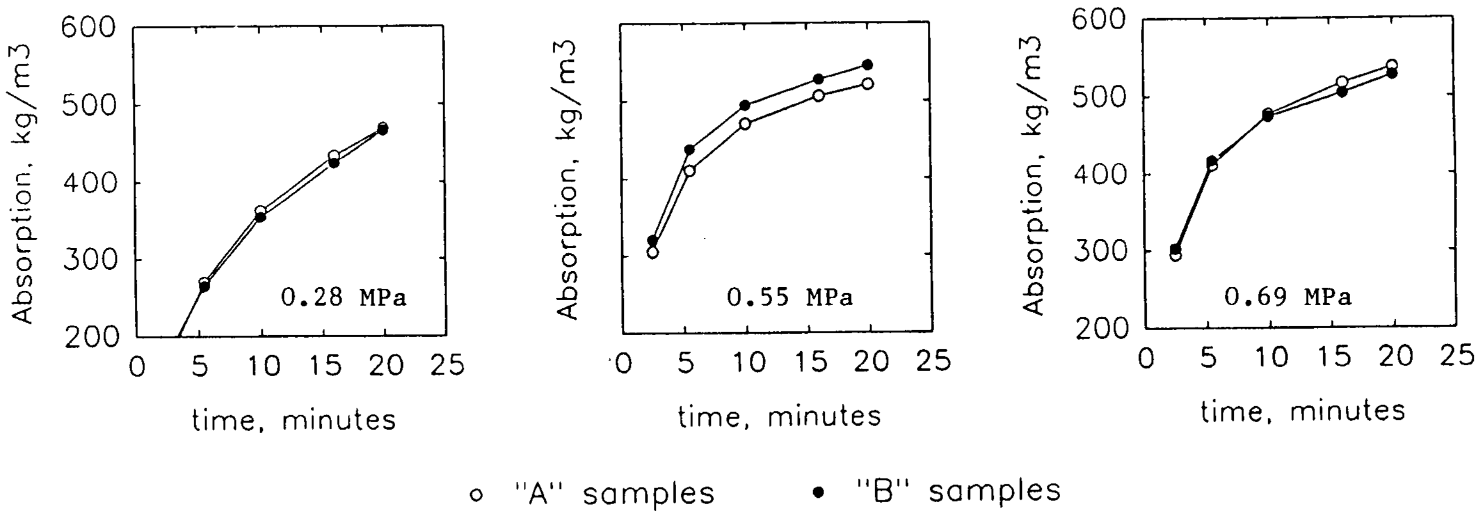

Fig.4.2 Absorption curves obtained from ponderosa pine controls, where both matched samples A and B were treated with hydraulic pressure at 0.28, 0.55 and 0.69 MPa.

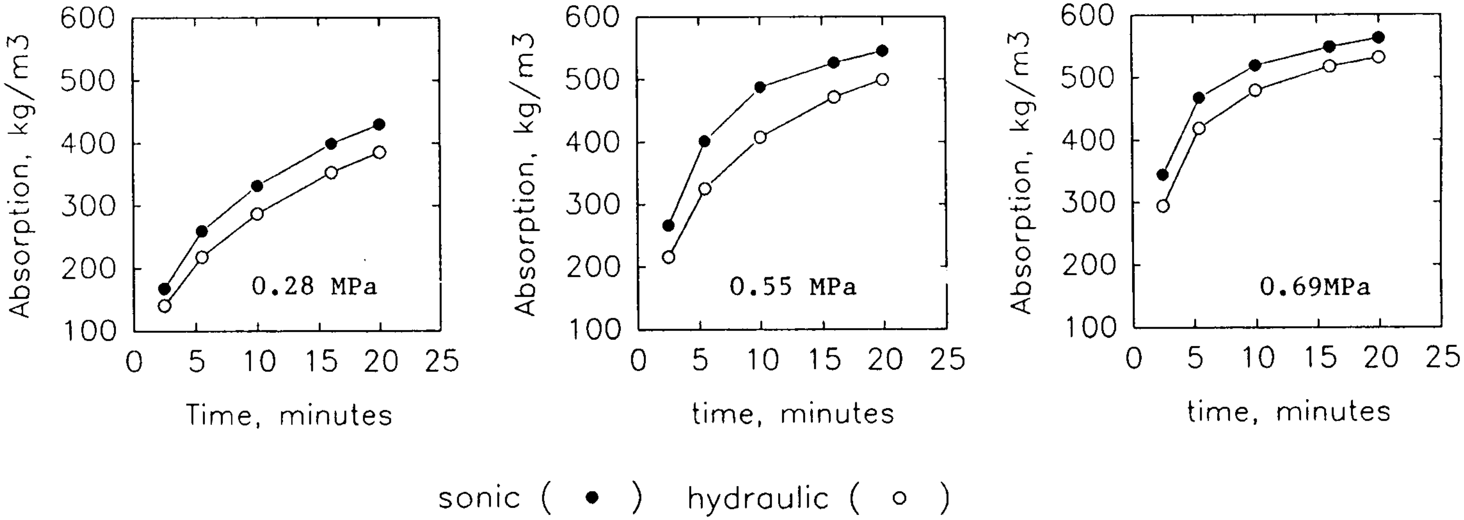

Fig.4.3 Absorption curves obtained from ponderosa pine, where sample A was treated with sonic pressure and the matched sample B was treated with hydraulic pressure, at 0.28, 0.55 and 0.69 MPa.

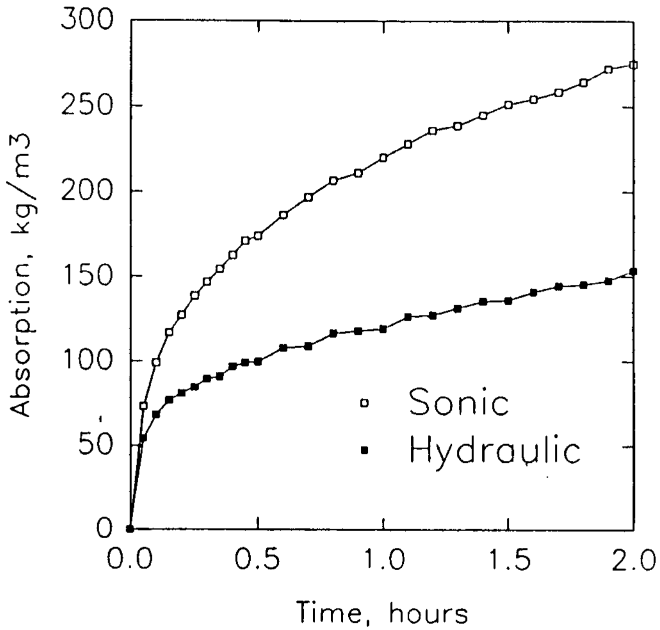

Fig4.4 Absorption curves obtained from sonic pressure applied to Douglas-fir sample A and hydraulic pressure applied to the matched sample B, at 0.55 MPa.

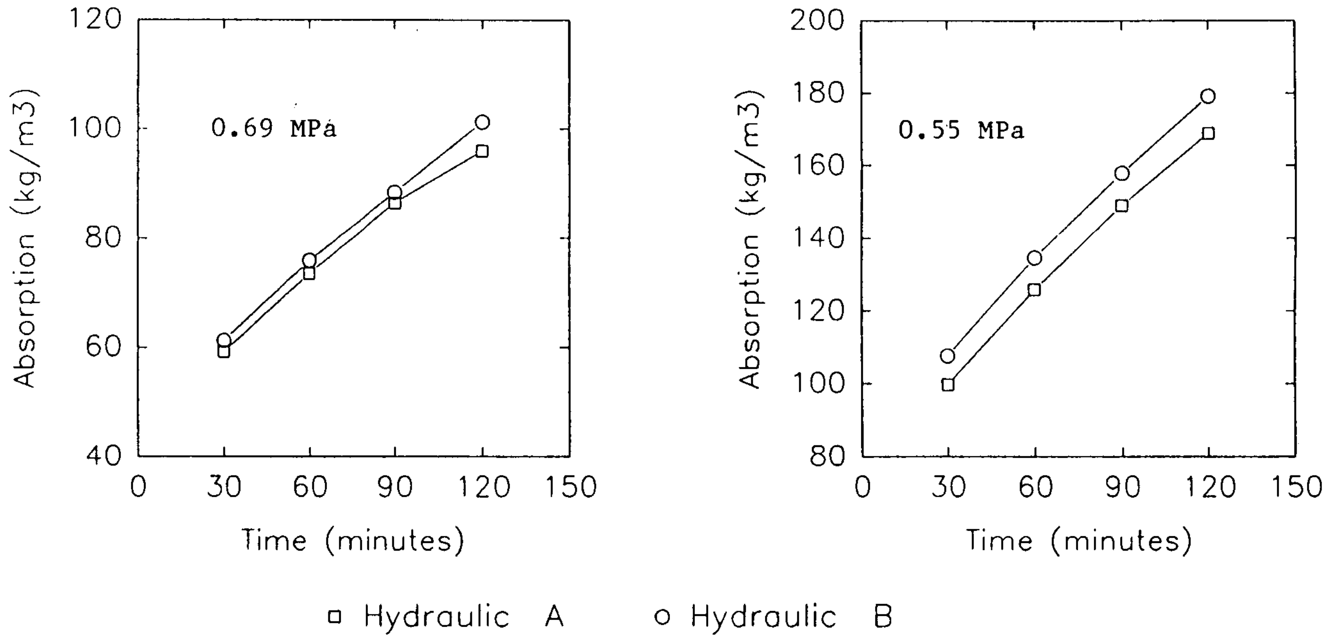

Fig.4.5 Absorption curves obtained from Douglas-fir control group, where both matched samples were treated with hydraulic pressure at 0.69 and 0.55 MPa.

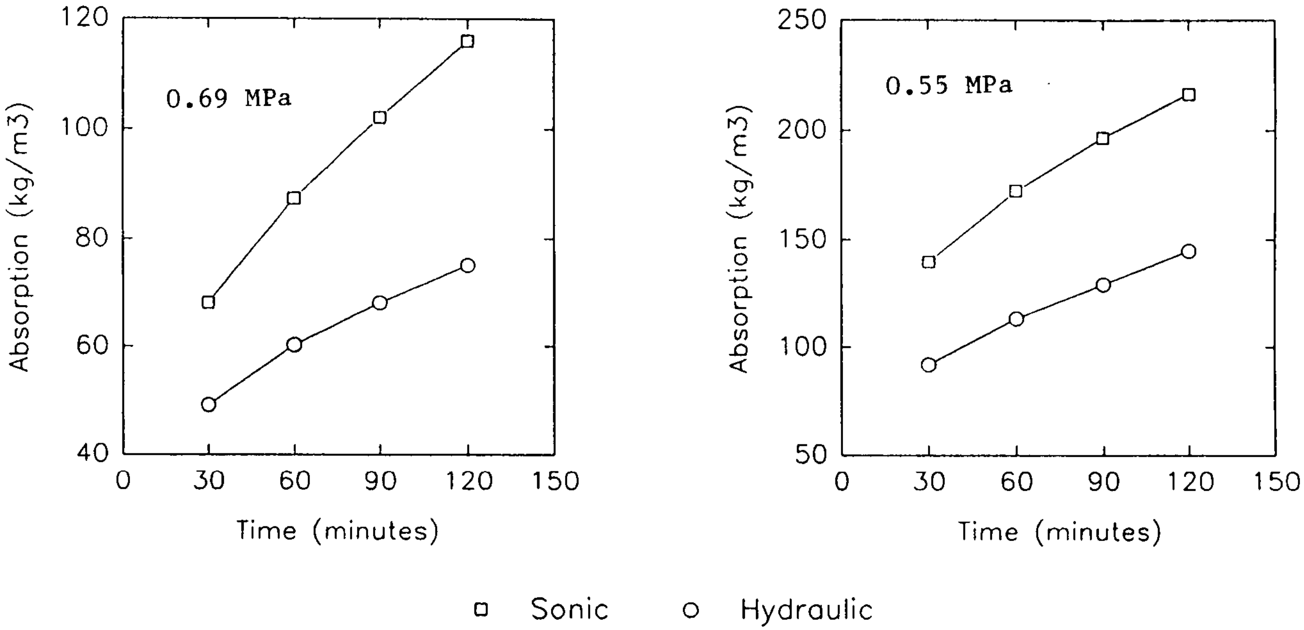

Fig.4.6 Absorption curves obtained from the Douglas-fir treatment group, where sample A was treated with sonic pressure and sample B was treated with hydraulic pressure, at 0.69 and 0.55 MPa.

4.2 Statistical Analysis

Experiments on wood must deal with the issue of variability of the substrate. In order to determine the variability, control and treatment groups were compared at all pressure conditions for both wood species. Paired comparisons were made in the control group to show that there was no statistically significant difference between samples A and B. In the treatment group, paired comparisons were used to determine if sonic treatment differed significantly from hydraulic treatment.

4.2.1 Analysis and results of Ponderosa pine data

Control groups were generated at 0.28, 0.55 and 0.69 MPa pressure conditions. Both the matched samples A and B were treated with hydraulic pressure. Average absorptions of ten A samples were compared to the average of ten B samples. Absorption data collected from group A and B at times 2.5, 5.5, 10, 16 and 20 minutes were subjected to a paired t-analysis (Table 4.1). The results showed that there were no statistically significant differences (2-sided p-values greater than 0.1) between paired samples at all pressure conditions, when treated hydraulically.

Table 4.1 Results of paired t-analysis for ponderosa pine control group.

Parameter	0.69 MPa					0.55 MPa				
	2.5 mt.	5.5 mt.	10 mt.	16 mt.	20 mt.	2.5 mt.	5.5 mt.	10 mt.	16 mt.	20 mt.
Average of Hyd. Abs. A - Hyd. Abs. B	7.95	6.45	4.19	12.5	10.47	15.7	27.6	23.6	21.2	23.9
Std. Dev. of Hyd. Abs. A - Hyd. Abs. B	43.89	52.23	49.39	45.15	41.83	32.3	43.24	43.43	55.45	61.92
Conf. Int. of Hyd. Abs. A - Hyd. Abs. B	-39 to 23	-44 to 31	-31 to 39	-20 to 45	-19 to 40	-7 to 39	-3 to 58	-7 to 55	-18 to 61	-20 to 68
2 sided p value	0.581	0.705	0.794	0.404	0.449	0.159	0.074	0.120	0.257	0.253
Null Hypothesis	Not Rej.	Not Rej.	Not Rej.	Not Rej.	Not Rej.	Not Rej.	Not Rej.	Not Rej.	Not Rej.	Not Rej.

Parameter	0.28 MPa				
	2.5 mt.	5.5 mt.	10 mt.	16 mt.	20 mt.
Average of Hyd. Abs. A - Hyd. Abs. B	9.07	5	7.71	9.92	1.35
Std. Dev. of Hyd. Abs. A - Hyd. Abs. B	27.63	33.65	40.85	33.19	36.98
Conf. Int. of Hyd. Abs. A - Hyd. Abs. B	-7 to 25	-14 to 24	-16 to 31	-9 to 29	-20 to 23
2 sided p value	0.241	0.588	0.492	0.283	0.893
Null Hypothesis	Not Rej.	Not Rej.	Not Rej.	Not Rej.	Not Rej.

Treatment groups were generated at the same pressure conditions as the control groups, i.e. 0.28, 0.55 and 0.69 MPa. Here sample A was treated with sonic pressure and sample B with hydraulic pressure. Average absorption of ten A samples were compared to the average of ten B samples. The null hypothesis was that the mean of the differences in absorptions between sample A and B would be equal to zero if both sonic and hydraulic treatments were not different. The results of the paired t-analysis (Table 4.2) showed that there were statistically significant differences between paired samples A and B at all pressure conditions (2-sided p-values less than 0.1), except at 16 and 20 minutes for 0.69 MPa. But the 2-sided p-values in these cases 0.12 and 0.15, respectively, were not too large. Samples reached near refusal stage by around 15 minutes of treatment at 0.69 MPa. This may explain why the results at 16 and 20 minutes were not statistically significant.

In order to illustrate the significance of sonic treatment over hydraulic treatment, a graph was created showing the difference between absorption of samples A and B and estimated difference at 90% confidence level calculated from the control group plotted at 2.5, 5.5, 10, 16 and 20 minutes (Figure 4.7). Actual differences higher than the estimate showed that there were significant differences between sonic and hydraulic treatments.

Table 4.2 Results of paired t-analysis for ponderosa pine treatment group.

Parameter	0.69 MPa					0.55 MPa				
	2.5 mt.	5.5 mt.	10 mt.	16 mt.	20 mt.	2.5 mt.	5.5 mt.	10 mt.	16 mt.	20 mt.
Average of Sonic Rtn. A - Hydraulic Rtn.B	51.79	49.33	38.95	31.69	40.61	52.37	76.12	70.43	54.84	46.46
Std. Dev. of Sonic Rtn.A - Hydraulic Rtn.B	40.05	42.69	50.9	58.12	80.54	35.03	50.3	47.7	48.46	47.4
Conf. Int. of Sonic Rtn.A - Hydraulic Rtn.B	23 to 80	19 to 80	3 to 75	-10 to 73	-17 to 98	27 to 77	40 to 112	36 to 105	20 to 90	13 to 80
2 sided p value	2.72 E-3	5.28 E-3	0.039	0.12	0.15	1.07 E-3	9.93 E-4	1.17 E-3	5.95 E-3	0.013
Null Hypothesis	Rejected	Rejected	Rejected	Not Rej	Not Rej	Rejected	Rejected	Rejected	Rejected	Rejected

Parameter	0.28 MPa				
	2.5 mt.	5.5 mt.	10 mt.	16 mt.	20 mt.
Average of Sonic Rtn. A - Hydraulic Rtn.B	26.6	41.27	44.65	45.96	44.36
Std. Dev. of Sonic Rtn.A - Hydraulic Rtn.B	31.09	45.02	56.56	69.43	73.38
Conf. Int. of Sonic Rtn.A - Hydraulic Rtn.B	4 to 49	9 to 73	4 to 85	-4 to 96	-8 to 97
2 sided p value	0.025	0.018	0.034	0.066	0.088
Null Hypothesis	Rejected	Rejected	Rejected	Rejected	Rejected

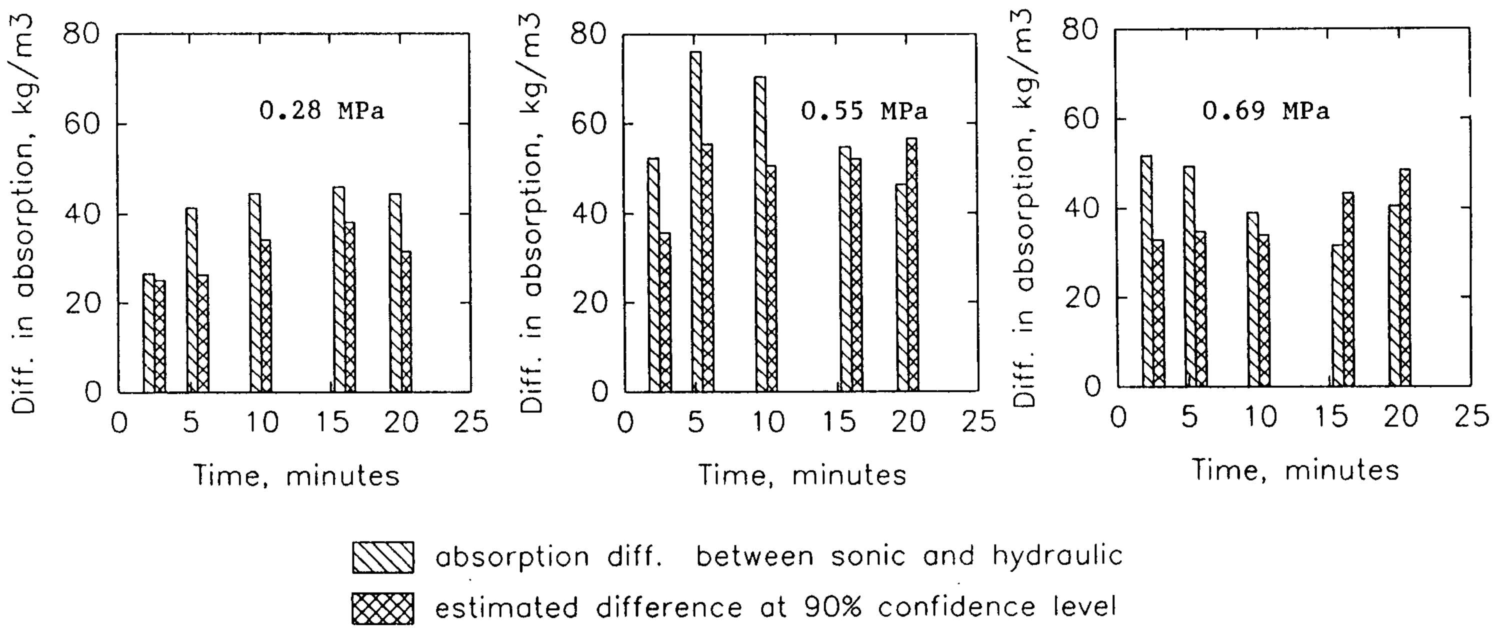

Fig.4.7 Draph showing actual difference in the mean absorption obtained from sonic and hydraulic tests; and the estimated difference calculated from the control group results with 90% confidence levels, at 0.28, 0.55 and 0.69 MPa for ponderosa pine samples.

4.2.2 Analysis and results of Douglas-fir data

Data from control groups treated at 0.55 and 0.69 MPa for 30, 60, 90 and 120 minutes were subjected to a paired t-analysis which showed that were no statistically significant differences (2-sided p-values greater than 0.1) between paired samples A and B at all pressure conditions, when treated hydraulically (Table 4.3).

Treatment groups were generated at the same pressure conditions as the control groups. Here sample A was treated with sonic pressure and sample B with hydraulic pressure. Paired t-analysis on data at 30, 60, 90 and 120 minutes (Table 4.4) showed that there were statistically significant differences between paired samples A and B at all pressure conditions (2-sided p-values less than 0.1).

In order to illustrate the significance of sonic treatment over hydraulic treatment, a graph was created comparing the difference between absorption of samples A and B and the estimated difference at 90% confidence level calculated from the control group (Figure 4.8). Actual differences higher than the estimate indicated significant difference between sonic and hydraulic treatments.

Table 4.3 Results of paired t-analysis for Douglas-fir control group.

Parameter	0.69 MPa				0.55 MPa			
	30 mt.	60 mt.	90 mt.	120 mt.	30 mt.	60 mt.	90 mt.	120 mt.
Average of Hydr. Abs. A - Hydraulic Abs.B	2.097	2.35	1.93	5.29	7.93	8.74	8.87	10.26
Std. Dev. of Hydr. Abs.A - Hydraulic Abs.B	12.04	16.19	20.04	21.98	15.09	19.93	23.86	24.72
Conf. Int. of Hydr. Abs.A - Hydraulic Abs.B	-9 to 5	-12 to 7	-14 to 10	-18 to 7	-1 to 17	-3 to 20	-5 to 23	-4 to 25
2 sided p value	0.595	0.658	0.767	0.466	0.131	0.199	0.270	0.222
Null Hypothesis	Not Rej	Not Rej.	Not Rej	Not rej.	Not Rej.	Not Rej.	Not Rej.	Not Rej.

Table 4.4 Results of paired t-analysis for the Douglas-fir treatment group.

Parameter	0.69 MPa				0.55 MPa			
	30 mt.	60 mt.	90 mt.	120 mt.	30 mt.	60 mt.	90 mt.	120 mt.
Average of Sonic Abs. A - Hydraulic Abs.B	19.04	27.15	33.96	40.89	47.73	58.96	67.4	71.97
Std. Dev. of Sonic Abs.A - Hydraulic Abs.B	24.23	28.15	28.15	29.81	32.53	40.46	44.84	49.21
Conf. Int. of Sonic Abs.A - Hydraulic Abs.B	5 to 33	11 to 43	18 to 50	24 to 58	29 to 67	35 to 82	41 to 93	43 to 100
2 sided p value	0.035	0.014	0.004	0.002	0.001	0.001	0.001	0.001
Null Hypothesis	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected

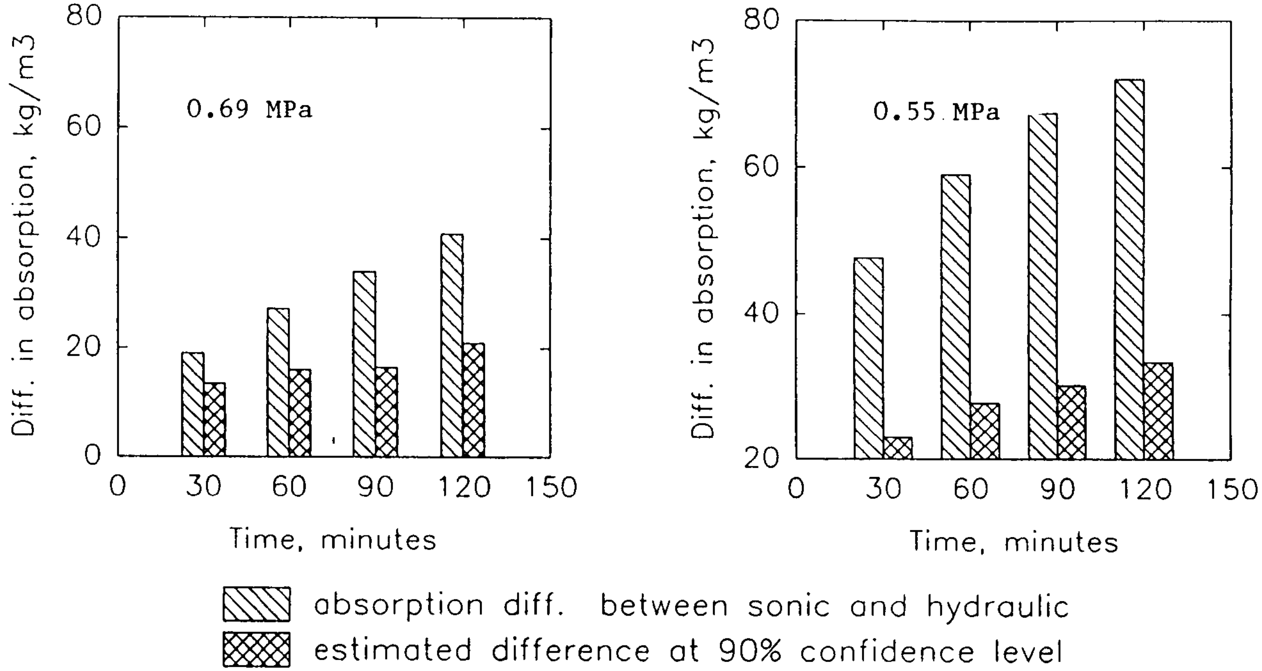

Fig.4.8 Graph showing actual difference in the mean absorption obtained from sonic and hydraulic tests; and the estimated difference calculated from control group results with 90% confidence levels , at 0.55 and 0.69 MPa for Douglas-fir samples.

4.3 Discussion

The effects of sonic treatment varied with the wood species. Rates of absorption were very high for ponderosa pine while those for Douglas-fir were much slower. Pit aspirations and blockage of tracheids during heartwood formation probably contributed to the relatively low permeability of the heartwood. These results conformed to previous observations (Wardrop and Davies, 1961; Bramhall, 1975; Bailey, 1965). Sonic treatment produced larger absorptions than hydraulic treatment for both species. The high peak pressures produced with the sonic treatments may have opened aspirated pits and hence increased the permeability.

Pressure also had a large influence on the treatment rates. Higher pressures produced larger absorptions in shorter time. The slopes of the absorption curves increased as the pressure increased. Similar absorption curves have been reported using static pressure conditions (Bramhall, 1975; Bailey, 1965; Buckman et al, 1933; Sucoff et al, 1965). Similarly at any particular pressure condition, initial absorption rates were much faster, then decreased as the treatment progressed. Sonic treatments produced consistently higher absorption rates than hydraulic treatments. This was very obvious in the case of Douglas-fir. Different relationships between pressure and flow rates may reflect varying thicknesses and diameters of the effective pit membranes. Increased pressure could cause a stretching of the thin pit membrane, resulting in an increase in pit diameter. The relative importance of this effect of pressure would vary for pit membranes of different thicknesses. Presence of large diameter unblocked resin canals in sapwood could also increase permeability. Sonic treatments produced consistently higher absorptions than hydraulic treatments. Even though not directly related, Hudson and Henriksson (1956) observed similar behavior in the OPM treatment, as did Burdell and Barnett (1969) with shock-wave pressure treatments. Peek (1987) observed similar results in refractory species by applying OPM. The earlier studies and results from this study strongly suggest that dynamic pressure conditions increase the permeability of the wood. Constantly alternating upper and lower peak pressures produced by the sonic generator may alter pit membranes or deaspirate the aspirated pits, thereby increasing the permeability.

From this study, it was clear that treatment time could be reduced by the sonic treatment. Reduced treatment time would result in added plant capacity and higher profit, if the extra cost of sonic equipment could be justified against savings in the cost of treatment.

Tests at low pressure (i.e. 0.28 MPa) were not attempted in Douglas-fir because this species is more difficult to treat and commercial operations typically employ higher pressures.

Douglas-fir results showed that sonic treatment gave almost double the absorption of hydraulic treatment after 2 hours. The potential for reducing treatment times through the use of sonic waves would markedly enhance the economics of Douglas-fir treatments, while producing a potentially better treated product. Further trials using longer pressure periods are suggested.

Bergervoet, 1994 suggested the following model to fit the absorption data obtained from sonic and hydraulic treatments.

Absorption = $A\ (1-e^{B(t+C)})$, where A, B and C are constants and t, the time. This model was evaluated on sonic and hydraulic absorption data at 0.69 MPa for ponderosa pine and Douglas-fir. The model fitted well for ponderosa pine where treatments reached the refusal stage, but did not fit very well for Douglas-fir. No further analyses were performed on the model since the refusal stage was not achieved with Douglas-fir due to equipment limitations.

CHAPTER 5
CONCLUSION

The results showed some clear indications that sonic treatment behaves differently than the hydraulic treatment. In ponderosa pine, even though sonic treatment is statistically significant in most of the cases, the actual difference in terms of absorption were not large.

In the case of Douglas-fir, there is a very significant difference between the two treatments. The sonic treatment produced much larger absorption than hydraulic treatment on this refractory species. This is a significant achievement.

It may hence be concluded that sonic treatment at 30 Hz. frequency was at least as effective as hydraulic treatment in ponderosa pine sapwood, while sonic treatment was significantly better than the hydraulic treatment in Douglas-fir heartwood.

Topics for further study include:

1. Study additional wood species, particularly those which are refractory since sonic treatment had the greatest effect on the refractory species tested
2. Determine the effect of frequencies on treatment
3. Determine the effect of sonic wave shape on treatment enhancement

4. Investigate the effect of solvent type(i.e. oil or water)
5. Determine the effect of sonic treatment on subsequent preservative distribution

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APPENDICES

APPENDIX 1
PONDEROSA PINE TEST DATA

Table A.1.1 Consolidated data for ponderosa pine sonic test at 0.28 MPa.

File no.		PP42002A	PP42002B	PP42004A	PP42004B	PP42008A	PP42008B	PP42018A	PP42018B	PP42023A	PP42023B
Dry wt.(kg)		0.2305	0.2300	0.2850	0.2815	0.2940	0.2890	0.3270	0.3040	0.3150	0.3095
Wet wt.(kg)		0.5720	0.4640	0.5115	0.5260	0.7270	0.6125	0.5310	0.4690	0.8050	0.8180
Volume(m3)		0.0006	0.0006	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Abs.wt.(kg/m3		601.83	413.07	313.91	337.26	597.02	443.47	282.52	230.48	675.61	705.55
Abs.vol.(kg/m		535.39	361.17	283.56	290.77	536.42	393.09	240.42	192.70	613.35	632.29
Diff. %		11.04	12.56	9.67	13.78	10.15	11.36	14.90	16.39	9.21	10.38
Time	0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	106.53	60.20	60.15	59.86	111.13	72.24	36.49	28.15	164.56	154.85
	2.5	155.70	90.29	85.93	79.11	160.28	99.87	62.25	43.30	224.40	212.91
	3.5	193.94	109.45	105.26	96.21	194.48	123.24	77.28	56.29	267.14	255.93
	4.5	221.26	125.86	120.30	109.04	222.26	142.36	90.16	64.95	299.20	288.19
	5.5	245.84	142.28	131.04	121.87	247.91	159.36	100.89	73.61	324.84	316.14
	6.5	267.70	155.96	141.78	132.56	269.28	176.36	109.48	80.11	344.08	339.80
	7.5	286.82	169.64	150.37	141.11	288.51	191.23	118.06	86.60	365.45	361.31
	8.5	305.94	183.32	158.96	149.66	307.75	201.86	124.50	93.10	382.55	378.51
	10.0	330.52	197.00	169.71	162.49	331.25	218.85	135.24	99.60	406.05	404.32
	12.0	360.57	216.16	182.59	177.46	361.17	240.10	148.12	110.42	433.84	434.43
	14.0	385.16	232.57	193.34	190.28	384.68	259.23	158.85	119.08	457.34	462.39
	16.0	407.01	248.99	206.22	203.11	408.19	276.22	169.58	127.74	478.72	486.04
	18.0	426.13	265.41	214.82	213.80	427.42	291.10	178.17	134.24	497.95	509.70
	20.0	445.25	279.09	225.56	224.49	446.66	305.97	186.75	142.90	517.18	531.21
	22.5	464.37	292.77	236.30	237.32	463.76	322.97	197.49	151.56	536.42	554.86
	25.0	480.76	309.19	247.04	250.15	482.99	337.84	206.07	160.22	555.65	576.37
	27.5	497.15	322.87	257.78	260.84	500.09	352.72	214.66	168.88	572.75	593.58
	30.0	513.54	336.55	266.37	271.53	515.05	367.59	223.25	175.37	589.85	608.63
	32.5	524.47	350.23	274.97	282.22	525.73	380.34	231.83	184.03	602.67	621.53
	35.0	535.39	361.17	283.56	290.77	536.42	393.09	240.42	192.70	613.35	632.29

Table A.1.1, Continued. Consolidated data for ponderosa pine sonic test at 0.28 MPa.

File no.		PP42030A	PP42030B	PP42032A	PP42032B	PP42045A	PP42045B	PP42046A	PP42047B	PP42047A	PP42047
Dry wt.(kg)		0.2065	0.2075	0.2370	0.2355	0.2755	0.2785	0.2970	0.3000	0.2980	0.3025
Wet wt.(kg)		0.5300	0.4745	0.6610	0.6270	0.6125	0.6435	0.8050	0.8230	0.8010	0.8200
Volume(m3)		0.0006	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Abs.wt.(kg/m3)		695.76	645.12	695.76	645.12	710.85	727.52	710.85	727.52	695.19	719.34
Abs.vol.(kg/m3)		628.24	569.57	628.24	569.57	650.68	666.24	650.68	666.24	631.96	663.60
Diff. %		9.71	11.71	9.71	11.71	8.46	8.42	8.46	8.42	9.10	7.75
Time	0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	124.63	127.71	124.63	127.71	160.50	148.77	160.50	148.77	156.38	135.74
	2.5	170.41	189.00	170.41	189.00	232.07	222.08	232.07	222.08	220.65	193.91
	3.5	251.80	229.87	251.80	229.87	279.79	273.83	279.79	273.83	263.50	237.00
	4.5	292.50	263.07	292.50	263.07	316.66	314.79	316.66	314.79	297.77	273.63
	5.5	323.02	293.72	323.02	293.72	344.86	349.29	344.86	349.29	327.76	303.79
	6.5	348.46	314.16	348.46	314.16	370.89	392.41	370.89	392.41	351.33	331.80
	7.5	368.80	334.59	368.80	334.59	392.58	401.04	392.58	401.04	374.89	357.66
	8.5	389.15	352.47	389.15	352.47	414.26	424.76	414.26	424.76	394.17	381.36
	10.0	414.59	378.01	414.59	378.01	438.12	454.94	438.12	454.94	419.88	411.52
	12.0	445.11	403.55	445.11	403.55	468.49	489.44	468.49	489.44	449.87	448.15
	14.0	470.54	429.09	470.54	429.09	494.51	519.63	494.51	519.63	475.58	484.77
	16.0	493.43	449.52	493.43	449.52	518.37	547.66	518.37	547.66	499.14	517.09
	18.0	511.24	467.40	511.24	467.40	540.06	573.53	540.06	573.53	520.56	542.95
	20.0	531.59	487.84	531.59	487.84	557.41	592.93	557.41	592.93	537.70	566.65
	22.5	551.93	505.71	551.93	505.71	579.10	616.65	579.10	616.65	559.12	592.50
	25.0	569.74	505.71	569.74	505.71	598.62	636.06	598.62	636.06	578.40	616.20
	27.5	587.54	526.15	587.54	526.15	613.81	648.99	613.81	648.99	593.40	635.59
	30.0	602.80	541.47	602.80	541.47	628.99	659.77	628.99	659.77	608.40	648.52
	32.5	615.52	556.80	615.52	556.80	639.83	664.09	639.83	664.09	621.25	657.14
	35.0	628.24	569.57	628.24	569.57	650.68	666.24	650.68	666.24	631.96	663.60

Table A.1.2 Consolidated data for ponderosa pine control group at 0.28 MPa.

File no.	PP40011A	PP40011B	PP40013A	PP40013B	PP40014A	PP40014B	PP40015A	PP40015B	PP40035A	PP40035B
Dry wt.(kg)	0.2800	0.2790	0.3015	0.3025	0.297	0.288	0.283	0.2785	0.31	0.303
Wet wt.(kg)	0.7405	0.7430	0.8125	0.8065	0.6985	0.705	0.7765	0.7385	0.7875	0.778
Volume(m3)	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Abs.wt.(kg/m3)	639.89	645.06	708.72	702.18	556.77	582.06	698.25	656.32	676.22	671.86
Abs.vol.(kg/m3	618.57	563.06	668.79	664.04	526.18	542.61	633.20	615.11	622.37	608.26
diff. %	3.33	12.71	5.64	5.43	5.49	6.78	9.32	6.28	7.96	9.47
Time 0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	187.00	165.00	188.10	165.85	44.71	53.66	39.42	24.30	43.84	78.82
2.5	230.00	200.00	274.95	230.42	92.00	99.09	81.04	72.44	109.61	135.75
3.5	250.06	208.37	335.79	279.22	141.43	148.85	122.65	121.48	160.03	188.30
4.5	295.29	237.89	391.90	320.25	175.82	183.47	173.03	165.65	206.07	240.85
5.5	330.61	266.55	422.00	351.12	201.62	211.59	221.65	225.28	230.18	275.89
6.5	354.09	291.12	463.23	387.24	227.41	237.56	250.78	245.16	263.07	302.16
7.5	379.93	313.31	494.01	413.75	248.90	259.19	280.35	276.08	291.57	326.25
8.5	407.28	333.35	520.88	438.80	268.25	282.99	304.88	298.17	320.06	360.40
10.0	430.55	360.07	554.20	472.49	287.59	306.57	328.32	322.46	346.37	385.36
12.0	469.31	391.53	583.23	511.36	311.24	330.59	348.47	342.78	372.68	411.64
14.0	493.87	419.55	600.42	544.19	339.18	358.71	375.63	370.17	409.95	451.05
16.0	517.99	443.68	626.22	571.83	369.27	391.17	409.58	401.97	442.83	481.70
18.0	535.01	465.88	643.63	594.93	397.21	414.96	440.24	431.79	473.52	512.36
20.0	554.17	486.13	651.59	613.72	423.01	440.93	460.17	454.98	493.25	529.88
22.5	571.84	508.33	658.25	631.86	440.20	464.73	483.17	478.39	512.98	547.39
25.0	591.22	528.37	660.40	645.25	468.57	492.85	503.76	497.39	530.52	562.72
27.5	603.71	536.99	662.77	653.67	487.49	510.16	526.17	521.24	550.25	573.67
30.0	608.88	550.35	666.64	658.85	505.97	523.14	547.56	542.44	567.79	582.42
32.5					513.93	533.31	567.06	568.06	583.13	586.80
35.0	614.70	555.73	667.71	662.09	516.08	536.12	590.93	577.56	596.29	591.18
37.5					521.88	538.50	606.26	595.23	605.05	595.56
40.0	618.57	563.06	668.79	664.04	524.03	540.88	616.78	603.40	616.02	600.16

Table A.1.2, Continued. Consolidated data for ponderosa pine control group at 0.28 MPa.

File no.		PP40040A	PP40040B	PP40041A	PP40041B	PP41043A	PP41043B	PP41049A	PP41049B	PP40051A	PP40051B
Dry wt.(kg)		0.335	0.302	0.3225	0.3235	0.3015	0.3035	0.2925	0.29	0.3365	0.3365
Wet wt.(kg)		0.7925	0.8025	0.8345	0.8255	0.809	0.769	0.806	0.825	0.83	0.8395
Volume(m3)		0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Abs.wt.(kg/m3)		647.90	707.93	722.01	708.66	701.27	649.12	703.79	734.18	698.89	710.07
Abs.vol.(kg/m3)		605.05	645.92	688.51	641.11	664.39	593.09	645.60	685.76	657.43	694.75
Diff. %		6.61	8.76	4.64	9.53	5.26	8.63	8.27	6.59	5.93	2.16
Time	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	61.38	74.45	52.46	52.51	129.58	130.55	181.21	185.05	54.88	50.49
	2.5	124.96	124.81	115.85	102.84	208.83	187.18	227.67	240.56	120.73	103.17
	3.5	168.80	181.73	177.05	159.73	258.52	231.70			164.63	158.05
	4.5	212.65	234.28	233.88	212.24	301.57	268.01	310.80	319.06	208.53	230.49
	5.5	241.14	269.32	273.22	247.25	340.76	300.00	343.03	345.16	262.31	278.78
	6.5	267.45	301.07	312.56	277.89	375.89	327.24	372.41	393.50	306.88	315.88
	7.5	304.72	339.38	351.91	306.33	404.37	352.52			335.85	344.41
	8.5	337.60	364.78	378.14	334.78	431.79	375.22	424.45	440.30	352.97	370.53
	10.0	366.10	402.88	406.55	364.32	469.27	405.70	451.01	474.33	376.24	392.48
	12.0	394.60	427.18	426.22	380.51	514.03	440.93	479.48	501.98	399.51	419.26
	14.0	438.45	457.62	454.64	401.95	552.37	470.97	499.87	525.38	430.24	450.00
	16.0	469.14	486.08	483.05	439.15	575.93	497.34	520.69	555.16	465.36	491.70
	18.0	491.06	514.55	504.91	462.78	599.49	520.25			496.09	520.24
	20.0	510.79	536.44	526.77	487.94	615.98	539.92	558.29	591.32	524.41	548.78
	22.5	530.52	558.34	544.25	512.23	637.19	559.37	579.53	618.97	546.36	570.73
	25.0	550.25	571.48	563.93	535.03	651.11	573.42			566.34	591.80
	27.5	565.59	586.80	585.78	554.90	657.32	582.50	616.71	659.39	585.87	610.90
	30.0	576.56	599.94	605.46	574.37	660.75	587.90	629.46	672.15	603.43	631.75
	32.5	580.94	613.08	625.13	588.37	662.25	590.93			623.19	653.04
	35.0	589.05	626.22	640.43	599.97	663.75	592.01	644.33	684.70	637.90	673.02
	37.5	595.19	636.07	655.73	614.85					649.97	683.77
	40.0	598.70	640.45	668.84	623.60	664.39	593.09	645.60	685.76	652.60	689.26

Table A.1.3 Consolidated data for ponderosa pine sonic test at 0.55 MPa.

File no.	PP82001A	PP82001B	PP82003A	PP82003B	PP82025A	PP82025B	PP82026A	PP82026B	PP82028A	PP82028B
Dry wt.(kg)	0.2015	0.2075	0.2760	0.2710	0.2780	0.2820	0.2145	0.2140	0.2065	0.2065
Wet wt.(kg)	0.5985	0.6035	0.7925	0.7760	0.5735	0.5515	0.4415	0.4170	0.5070	0.4605
Volume(m3)	0.0005	0.0005	0.0007	0.0007	0.0007	0.0007	0.0005	0.0005	0.0005	0.0005
Abs.wt.(kg/m3)	755.98	755.75	709.39	702.78	411.16	374.70	414.69	371.73	577.40	485.43
Abs.vol.(kg/m3)	687.71	701.07	636.53	629.86	368.79	340.49	385.10	340.60	527.15	438.42
Diff. %	9.03	7.23	10.27	10.38	10.30	9.13	7.14	8.37	8.70	9.69
Time 0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	268.59	233.69	244.82	237.28	122.93	109.91	141.58	96.50	193.59	154.04
2.5	422.07	352.01	406.61	332.19	166.06	146.54	189.72	139.08	256.13	201.44
3.5	507.67	428.93	504.54	392.58	194.10	174.56	218.03	167.46	294.85	231.06
4.5	563.75	482.17	564.15	437.88	215.67	193.95	240.69	190.17	324.63	257.72
5.5	602.12	523.58	600.34	470.24	235.08	213.35	260.51	210.04	348.46	278.46
6.5	628.68	556.12	621.63	498.28	250.17	226.28	274.66	224.23	369.30	296.23
7.5	649.34	582.75	630.14	522.01	263.11	239.21	288.82	238.42	387.17	311.04
8.5	661.15	606.41	634.40	541.42	276.05	249.98	302.98	249.77	402.06	325.85
10.0	672.96	635.99	634.40	562.99	291.15	265.07	317.14	266.80	425.89	343.63
12.0	678.86	665.57	636.53	586.72	310.56	284.46	334.13	283.83	449.72	367.33
14.0	684.76	683.32	636.53	603.97	327.81	299.55	348.29	300.86	470.56	388.06
16.0	687.71	695.16	636.53	614.76	342.91	314.63	362.44	315.06	491.41	405.83
18.0	687.71	698.11	636.53	623.39	355.85	327.56	373.77	329.25	509.28	423.61
20.0	687.71	701.07	636.53	629.86	368.79	340.49	385.10	340.60	527.15	438.42

Table A.1.3, Continued. Consolidated data for ponderosa pine sonic test at 0.55 MPa.

File no.	PP82033A	PP82033B	PP82048A	PP82048B	PP82052A	PP82052B	PP82055A	PP82055B	PP82066A	PP82066B
Dry wt.(kg)	0.2785	0.2765	0.2860	0.3015	0.2885	0.3085	0.3280	0.3125	0.316	0.3045
Wet wt.(kg)	0.8100	0.6885	0.5235	0.5020	0.7180	0.7275	0.8410	0.7830	0.8435	0.8145
Volume(m3)	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Abs.wt.(kg/m3)	332.24	279.72	332.24	279.72	718.89	654.79	718.89	654.79	737.10	714.59
Abs.vol.(kg/m3)	307.90	253.00	307.90	253.00	653.80	591.05	653.80	591.05	654.10	634.16
Diff. %	7.33	9.55	7.33	9.55	9.05	9.73	9.05	9.73	11.26	11.25
Time 0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	88.90	64.87	88.90	64.87	234.59	194.14	234.59	194.14	173.27	143.34
2.5	130.10	90.82	130.10	90.82	354.05	269.64	354.05	269.64	301.06	232.38
3.5	158.28	110.28	158.28	110.28	434.42	321.41	434.42	321.41	381.20	297.53
4.5	177.80	125.42	177.80	125.42	488.72	360.24	488.72	360.24	437.51	345.31
5.5	195.15	140.56	195.15	140.56	529.99	392.60	529.99	392.60	478.66	388.75
6.5	208.15	151.37	208.15	151.37	558.23	420.64	558.23	420.64	511.15	419.15
7.5	219.00	162.18	219.00	162.18	582.12	442.21	582.12	442.21	539.31	447.39
8.5	229.84	170.83	229.84	170.83	599.50	461.62	599.50	461.62	558.80	471.28
10.0	245.02	183.80	245.02	183.80	619.05	487.51	619.05	487.51	584.79	503.85
12.0	260.19	201.10	260.19	201.10	636.42	517.71	636.42	517.71	612.95	540.77
14.0	275.37	216.24	275.37	216.24	645.11	539.28	645.11	539.28	630.28	571.18
16.0	286.21	229.21	286.21	229.21	649.46	560.85	649.46	560.85	643.27	595.07
18.0	299.22	242.19	299.22	242.19	653.80	575.95	653.80	575.95	649.77	616.79
20.0	307.90	253.00	307.90	253.00	653.80	591.05	653.80	591.05	654.10	634.16

Table A.1.4 Consolidated data for ponderosa pine control group at 0.55 MPa.

File no.	PP80053A	PP80053B	PP80059A	PP80059B	PP80062A	PP80062B	PP80073A	PP80073B	PP80079A	PP80079B
Dry wt.(kg)	0.3230	0.3105	0.3430	0.3335	0.3185	0.3265	0.2190	0.2185	0.3060	0.3290
Wet wt.(kg)	0.8475	0.8480	0.7285	0.7700	0.8370	0.8350	0.4165	0.4430	0.7530	0.8495
Volume(m3)	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0006	0.0006	0.0007	0.0007
Abs.wt.(kg/m3	726.37	740.96	551.36	625.95	739.25	725.38	347.61	395.08	622.38	718.35
Abs.vol.(kg/m	674.02	675.20	501.02	569.02	685.07	672.17	316.46	360.06	569.75	654.59
Diff. %	7.21	8.87	9.13	9.10	7.33	7.34	8.96	8.86	8.46	8.88
Time 0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	283.35	318.37	150.75	153.37	335.91	331.66	87.30	100.92	135.96	181.83
2.5	392.82	450.85	201.74	202.27	459.66	462.12	114.58	130.93	196.39	216.06
3.5	461.51	536.32	230.56	237.83	537.01	539.50	133.68	152.75	239.55	312.32
4.5	513.03	589.73	254.94	266.73	587.84	590.36	150.04	171.84	274.08	352.96
5.5	551.66	626.06	274.89	288.96	623.19	627.95	160.96	185.48	299.98	387.19
6.5	581.72	649.56	292.63	311.18	649.71	650.06	171.87	199.12	323.72	415.00
7.5	605.33	662.38	308.15	331.19	665.18	663.32	182.78	210.03	345.30	438.53
8.5	624.65	668.79	321.45	344.52	676.23	667.75	190.97	220.94	364.73	459.92
10.0	643.97	673.07	339.18	366.75	682.86	669.96	204.61	237.31	390.62	485.59
12.0	661.14	675.20	363.57	391.20	685.07	672.17	218.25	250.95	414.36	515.54
14.0	669.72	675.20	379.09	413.43	685.07	672.17	229.16	261.86	438.10	543.35
16.0	674.02	675.20	396.82	433.43	685.07	672.17	240.07	272.77	457.53	564.74
18.0	674.02	675.20	410.13	455.66	685.07	672.17	250.98	297.32	474.79	583.99
20.0	674.02	675.20	423.43	471.22	685.07	672.17	261.90	305.50	489.90	603.25
22.5	674.02	675.20	438.94	489.00	685.07	672.17	272.81	316.41	507.16	616.08
25.0	674.02	675.20	452.25	509.01	685.07	672.17	280.99	327.32	520.11	624.64
27.5	674.02	675.20	467.76	524.57	685.07	672.17	289.18	338.23	535.22	633.20
30.0	674.02	675.20	478.85	540.13	685.07	672.17	308.27	349.15	548.17	643.89
32.5	674.02	675.20	489.93	555.69	685.07	672.17	316.46	360.06	558.96	650.31
35.0	674.02	675.20	501.02	569.02	685.07	672.17	316.46	360.06	569.75	654.59

Table A.1.4, Continued. Consolidated data for ponderosa pine control group at 0.55 MPa.

File no.	PP80082A	PP80082	PP80085A	PP80085B	PP80087A	PP80087B	PP80090A	PP80090B	PP80092A	PP80092B
Dry wt.(kg)	0.3195	0.3045	0.2945	0.2910	0.3160	0.3255	0.3245	0.3220	0.2810	0.3045
Wet wt.(kg)	0.8310	0.8330	0.7095	0.6220	0.8410	0.8430	0.8465	0.8355	0.5515	0.6975
Volume(m3)	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Abs.wt.(kg/m3)	579.90	459.88	579.90	459.88	720.37	717.65	720.37	717.65	389.16	561.26
Abs.vol.(kg/m3)	526.31	417.78	526.31	417.78	663.10	656.37	663.10	656.37	354.56	515.78
Diff. %	9.24	9.15	9.24	9.15	7.95	8.54	7.95	8.54	8.89	8.10
Time 0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	116.96	96.91	116.96	96.91	284.49	335.77	284.49	335.77	0.00	0.00
2.5	155.94	133.52	155.94	133.52	382.89	450.58	382.89	450.58	89.20	117.32
3.5	181.94	155.05	181.94	155.05	453.48	517.73	453.48	517.73	118.19	154.95
4.5	207.93	174.43	207.93	174.43	500.53	563.22	500.53	563.22	138.26	179.30
5.5	229.59	191.66	229.59	191.66	534.76	595.71	534.76	595.71	156.10	199.23
6.5	251.24	208.89	251.24	208.89	564.71	619.54	564.71	619.54	167.25	219.15
7.5	266.41	221.81	266.41	221.81	586.10	636.87	586.10	636.87	178.40	236.86
8.5	285.90	234.73	285.90	234.73	605.35	643.37	605.35	643.37	189.55	252.35
10.0	307.56	251.96	307.56	251.96	626.74	652.04	626.74	652.04	200.70	267.85
12.0	335.71	271.34	335.71	271.34	645.99	654.20	645.99	654.20	214.08	289.99
14.0	359.54	290.72	359.54	290.72	656.68	656.37	656.68	656.37	227.46	316.55
16.0	383.36	307.95	383.36	307.95	660.96	656.37	660.96	656.37	243.07	340.90
18.0	405.02	320.87	405.02	320.87	663.10	656.37	663.10	656.37	256.45	363.04
20.0	422.35	335.95	422.35	335.95	663.10	656.37	663.10	656.37	269.83	382.96
22.5	446.18	351.02	446.18	351.02	663.10	656.37	663.10	656.37	280.98	402.88
25.0	463.50	366.10	463.50	366.10	663.10	656.37	663.10	656.37	294.35	427.23
27.5	483.00	381.17	483.00	381.17	663.10	656.37	663.10	656.37	307.73	447.15
30.0	498.16	394.09	498.16	394.09	663.10	656.37	663.10	656.37	318.88	467.08
32.5	513.32	404.86	513.32	404.86	663.10	656.37	663.10	656.37	330.03	487.00
35.0	526.31	417.78	526.31	417.78	663.10	656.37	663.10	656.37	341.18	500.28

Table A.1.5 Consolidated data for ponderosa pine sonic test at 0.69 MPa.

File no.		PP12061A	PP12061B	PP12065A	PP12065B	PP12071A	PP12071B	PP12072A	PP12072B	PP12077A	PP12077B
Dry wt.(kg)		0.359	0.3465	0.3085	0.303	0.234	0.2235	0.183	0.1935	0.2345	0.2505
Wet wt.(kg)		0.7985	0.8365	0.8455	0.841	0.6205	0.6155	0.378	0.3525	0.422	0.47
Volume(m3)		0.0007	0.0007	0.0007	0.0007	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006
Abs.wt.(kg/m3)		612.02	677.21	745.70	750.42	730.61	741.65	397.01	327.52	303.43	356.66
Abs.vol.(kg/m3)		569.83	612.67	669.39	672.38	729.57	671.55	362.91	300.13	301.00	322.37
Diff. %		6.89	9.53	10.23	10.40	0.14	9.45	8.59	8.36	0.80	9.61
Time	0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	213.69	197.08	307.79	239.98	336.95	313.78	113.61	89.40	90.30	100.74
	2.5	278.44	269.92	462.76	358.89	498.10	469.21	157.79	121.33	127.93	136.00
	3.5	321.61	321.33	548.86	441.04	588.93	563.05	189.34	143.68	155.52	158.67
	4.5	356.14	359.89	600.52	501.58	644.60	618.77	211.43	159.64	180.60	176.30
	5.5	382.04	394.17	632.80	540.50	679.76	648.09	230.37	175.61	190.64	193.93
	6.5	405.79	419.87	652.18	579.41	700.27	662.76	246.15	188.38	205.69	206.52
	7.5	425.21	443.44	662.94	605.36	711.99	665.69	258.77	201.15	215.72	219.11
	8.5	442.48	467.00	665.09	626.98	720.78	668.62	271.39	210.73	225.75	229.19
	10.0	466.22	499.13	667.24	648.60	726.64	671.55	287.17	226.69	238.29	244.30
	12.0	494.28	533.41	667.24	665.89	729.57	671.55	306.10	242.66	253.34	261.93
	14.0	515.87	561.26	669.39	670.21	729.57	671.55	321.88	258.62	268.39	279.56
	16.0	535.29	584.82	669.39	672.38	729.57	671.55	337.66	271.39	280.94	294.67
	18.0	552.56	599.82	669.39	672.38	729.57	671.55	350.28	287.36	293.48	309.78
	20.0	569.83	612.67	669.39	672.38	729.57	671.55	362.91	300.13	301.00	322.37

Table A.1.5, Continued. Consolidated data for ponderosa pine sonic test at 0.69 MPa.

File no.	PP12078A	PP12078B	PP12080A	PP12080B	PP12081A	PP12081B	PP12089A	PP12089B	PP12091A	PP12091B
Dry wt.(kg)	0.1845	0.1820	0.276	0.289	0.3065	0.3145	0.3405	0.332	0.3245	0.3135
Wet wt.(kg)	0.4960	0.4925	0.6835	0.6315	0.8495	0.8375	0.836	0.8395	0.6935	0.565
Volume(m3)	0.0004	0.0004	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Abs.wt.(kg/m3)	739.09	737.41	570.78	483.74	752.08	723.13	510.68	349.78	510.68	349.78
Abs.vol.(kg/m3)	665.65	669.96	531.91	440.03	699.86	657.94	459.06	314.73	459.06	314.73
Diff. %	9.94	9.15	6.81	9.04	6.94	9.02	10.11	10.02	10.11	10.02
Time 0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	279.50	206.14	132.44	94.14	161.01	261.46	154.45	86.23	154.45	86.23
2.5	419.25	338.66	212.77	148.87	517.38	499.35	216.66	127.19	216.66	127.19
3.5	500.16	423.33	262.70	188.27	671.96	606.50	255.27	153.05	255.27	153.05
4.5	555.32	478.54	299.61	218.92	691.28	642.94	283.16	174.61	283.16	174.61
5.5	592.10	522.71	330.00	243.00	695.57	653.65	306.75	189.70	306.75	189.70
6.5	617.84	555.84	358.23	264.89	697.72	655.80	323.92	204.79	323.92	204.79
7.5	647.27	585.29	379.94	282.41	699.86	657.94	341.08	215.57	341.08	215.57
8.5	658.30	603.70	399.48	302.11	699.86	657.94	356.09	226.35	356.09	226.35
10.0	661.98	629.47	425.53	328.38	699.86	657.94	375.40	241.44	375.40	241.44
12.0	665.65	651.55	453.76	354.65	699.86	657.94	396.85	260.84	396.85	260.84
14.0	665.65	662.60	479.81	380.92	699.86	657.94	414.01	275.93	414.01	275.93
16.0	665.65	669.96	499.35	407.19	699.86	657.94	431.17	291.02	431.17	291.02
18.0	665.65	669.96	516.72	422.52	699.86	657.94	446.19	303.95	446.19	303.95
20.0	665.65	669.96	531.91	440.03	699.86	657.94	459.06	314.73	459.06	314.73

Table A.1.6 Consolidated data for ponderosa pine control group at 0.69 MPa.

File no.	PP10056A	PP10056B	PP10057A	PP10057B	PP10060A	PP10060B	PP10063A	PP10063B	PP10064A	PP10064
Dry wt.(kg)	0.3125	0.3120	0.3150	0.3255	0.2185	0.2270	0.2720	0.2705	0.2605	0.2530
Wet wt.(kg)	0.8495	0.8525	0.8430	0.8500	0.4900	0.5305	0.5930	0.6065	0.7010	0.6950
Volume(m3)	0.0007	0.0007	0.0007	0.0007	0.0006	0.0006	0.0007	0.0007	0.0006	0.0006
Abs.wt.(kg/m3	745.65	754.49	737.62	727.64	461.46	521.78	447.20	469.93	734.69	742.16
Abs.vol.(kg/m	665.04	670.73	677.75	664.45	429.42	484.99	414.60	431.39	661.81	671.47
Diff. %	10.81	11.10	8.12	8.68	6.94	7.05	7.29	8.20	9.92	9.52
Time 0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	318.53	335.37	194.88	247.29	121.19	114.59	112.29	101.89	341.25	309.71
2.5	469.19	482.49	292.32	341.90	160.70	154.56	151.16	134.40	465.33	434.63
3.5	555.28	573.37	348.62	406.41	189.68	181.21	177.07	160.42	540.30	515.31
4.5	606.93	629.62	396.26	451.57	210.76	205.19	198.66	179.93	589.42	569.97
5.5	639.22	657.75	433.07	490.28	229.20	221.18	215.94	197.27	620.45	609.00
6.5	654.28	666.40	463.39	522.53	247.64	234.50	228.90	212.45	641.13	637.63
7.5	660.74	668.57	493.70	546.18	258.18	250.49	241.85	225.45	651.47	653.25
8.5	665.04	668.57	515.35	567.69	271.35	266.48	252.65	238.46	656.64	661.06
10.0	665.04	670.73	541.34	591.34	287.16	282.47	267.77	255.80	659.22	666.26
12.0	665.04	670.73	571.65	619.30	305.60	309.12	287.20	275.31	661.81	668.86
14.0	665.04	670.73	597.64	636.50	318.77	330.43	304.48	294.82	661.81	671.47
16.0	665.04	670.73	621.46	649.40	334.58	349.09	317.43	312.16	661.81	671.47
18.0	665.04	670.73	638.78	658.00	347.75	367.74	332.55	327.34	661.81	671.47
20.0	665.04	670.73	649.61	662.30	360.92	381.07	343.34	342.51	661.81	671.47
22.5	665.04	670.73	660.43	664.45	374.09	402.38	356.30	357.69	661.81	671.47
25.0	665.04	670.73	669.09	664.45	387.27	421.04	371.42	375.03	661.81	671.47
27.5	665.04	670.73	675.59	664.45	397.80	439.69	382.21	390.21	661.81	671.47
30.0	665.04	670.73	677.75	664.45	410.98	455.68	393.01	405.38	661.81	671.47
32.5	665.04	670.73	677.75	664.45	421.51	469.00	403.81	418.39	661.81	671.47
35.0	665.04	670.73	677.75	664.45	429.42	484.99	414.60	431.39	661.81	671.47

Table A.1.6, Continued. Consolidated data for ponderosa pine control group at 0.69 MPa.

File no.		PP10070A	PP10070B	PP10076A	PP10076B	PP10083A	PP10083B	PP10088A	PP10088B	PP10094A	PP10094B
Dry wt.(kg)		0.3100	0.2990	0.2625	0.2480	0.3255	0.3050	0.2905	0.2715	0.2800	0.2700
Wet wt.(kg)		0.7080	0.7025	0.6800	0.6805	0.8565	0.8230	0.6730	0.5545	0.6235	0.6075
Volume(m3)		0.0006	0.0006	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Abs.wt.(kg/m3)		677.05	686.89	738.27	720.20	738.27	720.20	476.91	467.06	476.91	467.06
Abs.vol.(kg/m3)		609.09	620.08	670.21	670.21	670.21	670.21	447.62	441.87	447.62	441.87
Diff. %		10.04	9.73	9.22	6.94	9.22	6.94	6.14	5.39	6.14	5.39
Time	0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	261.04	324.55	200.42	163.78	200.42	163.78	122.66	128.70	122.66	128.70
	2.5	334.87	416.90	299.55	247.83	299.55	247.83	159.25	173.75	159.25	173.75
	3.5	384.96	477.59	370.66	303.86	370.66	303.86	189.38	199.49	189.38	199.49
	4.5	424.51	517.17	420.23	344.80	420.23	344.80	210.90	220.94	210.90	220.94
	5.5	456.16	546.19	463.33	377.13	463.33	377.13	230.27	238.10	230.27	238.10
	6.5	482.52	567.30	493.50	402.99	493.50	402.99	245.33	253.11	245.33	253.11
	7.5	503.62	585.77	523.67	426.69	523.67	426.69	260.39	268.13	260.39	268.13
	8.5	522.07	596.33	549.53	446.09	549.53	446.09	273.31	278.85	273.31	278.85
	10.0	548.44	606.88	579.70	469.80	579.70	469.80	290.52	296.01	290.52	296.01
	12.0	580.08	617.44	612.03	499.97	612.03	499.97	309.89	313.17	309.89	313.17
	14.0	598.54	620.08	637.89	525.83	637.89	525.83	327.11	332.48	327.11	332.48
	16.0	606.45	620.08	655.13	547.38	655.13	547.38	344.32	345.35	344.32	345.35
	18.0	609.09	620.08	665.90	566.77	665.90	566.77	357.23	356.07	357.23	356.07
	20.0	609.09	620.08	668.06	581.86	668.06	581.86	372.30	368.94	372.30	368.94
	22.5	609.09	620.08	670.21	601.25	670.21	601.25	387.36	383.96	387.36	383.96
	25.0	609.09	620.08	670.21	616.34	670.21	616.34	400.27	396.83	400.27	396.83
	27.5	609.09	620.08	670.21	631.42	670.21	631.42	413.19	409.70	413.19	409.70
	30.0	609.09	620.08	670.21	642.20	670.21	642.20	426.10	420.42	426.10	420.42
	32.5	609.09	620.08	670.21	648.66	670.21	648.66	436.86	431.15	436.86	431.15
	35.0	609.09	620.08	670.21	657.28	670.21	657.28	447.62	441.87	447.62	441.87

APPENDIX 2
DOUGLAS-FIR TEST DATA

Table A.2.1 Consolidated data for Douglas-fir sonic test at 0.55 MPa.

		Sonic	Hydr.	Sonic	Hydr.
File		820302A	820301A	820304A	120303A
Dry wt. (kg.)		0.3360	0.3265	0.3330	0.3375
Wet wt. (kg.)		0.4950	0.4485	0.5375	0.4175
Volume (m3)		7.1E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3		223.60	174.70	292.60	114.37
Abs. vol. kg/m3		176.38	141.67	252.98	88.06
Diff. %		21.12	18.91	13.54	23.01
Time (hr.)	0	.000.00	0.00	0.00	0.00
	0.05	44.43	47.07	62.10	29.66
	0.10	59.24	57.13	90.87	38.33
	0.15	73.16	64.90	107.31	39.24
	0.20	83.93	73.58	120.10	46.08
	0.25	87.07	78.61	126.95	47.45
	0.30	95.15	82.26	134.25	47.91
	0.35	102.78	83.18	142.47	49.28
	0.40	104.57	85.46	145.67	53.38
	0.45	111.75	90.94	152.06	56.12
	0.50	112.65	92.32	159.37	56.12
	0.60	119.83	99.17	168.96	56.58
	0.70	122.08	101.46	175.81	59.77
	0.80	130.15	106.03	181.29	64.33
	0.90	131.95	109.68	189.51	64.79
	1.00	140.03	110.60	194.99	67.53
	1.10	146.76	118.37	198.18	72.09
	1.20	148.55	119.28	206.86	73.46
	1.30	154.39	120.19	213.71	73.91
	1.40	157.08	126.59	218.73	74.83
	1.50	162.92	128.42	224.67	78.02
	1.60	165.16	129.33	229.69	82.58
	1.70	166.51	135.27	234.26	83.50
	1.80	167.85	137.56	237.91	83.95
	1.90	173.24	138.02	244.76	84.41
	2.00	176.38	141.67	252.98	88.06

Table A.2.1, Continued. Consolidated data for Douglas-fir sonic test at 0.55 MPa.

	Sonic	Hydr.	Sonic	Hydr.
File	820305A	820306A	820308A	820307A
Dry wt. (kg.)	0.3380	0.3385	0.3425	0.3415
Wet wt. (kg.)	0.5640	0.4690	0.5405	0.5060
Volume (m3)	7.0E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3	321.81	185.93	281.59	235.14
Abs. vol. kg/m3	274.94	153.69	259.62	196.16
Diff. %	14.57	17.34	7.80	16.58
Time (hr.) 0	.000.00	0.00	0.00	0.00
0.05	73.17	54.11	80.34	67.52
0.10	99.07	68.21	103.94	82.11
0.15	116.79	76.85	117.55	88.96
0.20	127.24	80.94	134.80	100.82
0.25	138.61	84.58	139.79	105.38
0.30	146.79	89.58	146.60	113.13
0.35	154.51	90.94	155.23	114.05
0.40	162.69	96.85	162.03	117.70
0.45	171.33	99.13	165.21	122.71
0.50	174.05	99.58	172.93	125.45
0.60	186.32	107.77	182.46	132.29
0.70	196.77	108.67	190.17	137.31
0.80	206.32	116.40	195.17	143.70
0.90	210.86	117.77	201.07	151.00
1.00	219.95	119.13	209.24	153.28
1.10	227.68	126.41	216.50	159.67
1.20	235.86	127.32	218.77	163.32
1.30	238.58	131.41	226.48	168.33
1.40	244.95	135.50	227.85	170.16
1.50	251.31	135.96	234.20	173.81
1.60	254.49	140.96	237.38	179.28
1.70	258.58	144.60	245.09	182.48
1.80	264.49	145.51	250.54	187.95
1.90	272.21	147.78	255.53	193.88
2.00	274.94	153.69	259.62	195.71

Table A.2.1, Continued. Consolidated data for Douglas-fir sonic test at 0.55 MPa.

	Sonic	Hydr.	Sonic	Hydr.
File	820310A	820309A	820312A	820311A
Dry wt. (kg.)	0.3440	0.3490	0.3440	0.3495
Wet wt. (kg.)	0.6465	0.5770	0.5775	0.5325
Volume (m3)	7.0E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3	430.65	324.91	332.20	261.37
Abs. vol. kg/m3	383.46	281.51	299.67	219.25
Diff. %	10.96	13.35	9.79	16.12
Time (hr.) 0.00	0.00	0.00	0.00	0.00
0.05	118.58	81.86	94.44	81.14
0.10	147.66	101.42	118.96	98.00
0.15	173.56	118.25	134.40	108.94
0.20	191.73	130.52	151.65	118.51
0.25	203.09	141.44	159.82	120.79
0.30	213.09	146.44	167.54	128.09
0.35	223.08	155.99	171.17	133.10
0.40	230.81	164.18	179.80	137.66
0.45	238.53	168.73	187.97	140.39
0.50	247.62	173.73	195.24	146.77
0.60	260.79	183.73	206.59	153.16
0.70	274.42	195.10	214.76	155.89
0.80	285.33	202.38	223.39	164.10
0.90	293.50	212.84	233.38	172.30
1.00	303.05	219.66	240.19	175.04
1.10	314.40	228.30	243.82	182.33
1.20	327.13	234.67	251.99	183.24
1.30	334.85	238.76	260.62	187.80
1.40	338.48	246.04	266.98	193.72
1.50	350.30	249.68	270.61	200.56
1.60	356.20	257.87	278.78	201.93
1.70	363.93	264.69	282.87	206.49
1.80	369.83	269.24	288.77	210.13
1.90	377.10	274.24	295.58	212.87
2.00	383.46	281.51	299.67	219.25

Table A.2.1, Continued. Consolidated data for Douglas-fir sonic test at 0.55 MPa.

	Sonic	Hydr.	Sonic	Hydr.
File	820314A	820313A	820402A	820401A
Dry wt. (kg.)	0.3565	0.3520	0.3270	0.3305
Wet wt. (kg.)	0.5890	0.5295	0.3850	0.3850
Volume (m3)	7.0E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3	330.71	252.50	83.05	77.73
Abs. vol. kg/m3	296.43	216.55	69.46	60.08
Diff. %	10.36	14.24	16.36	22.70
Time (hr.) 0	.000.00	0.00	0.00	0.00
0.05	99.42	71.73	31.99	15.02
0.10	122.11	82.63	32.90	18.21
0.15	138.91	91.71	33.36	22.30
0.20	152.07	100.79	37.02	24.12
0.25	161.61	108.96	38.84	24.58
0.30	167.05	111.68	41.13	25.04
0.35	176.13	118.49	41.59	28.22
0.40	183.85	121.67	41.59	31.41
0.45	186.57	127.57	42.04	33.23
0.50	194.29	129.84	42.96	33.23
0.60	203.37	137.10	46.16	35.05
0.70	212.45	145.73	49.81	40.06
0.80	222.44	148.00	50.73	41.42
0.90	230.61	155.72	51.18	41.88
1.00	238.32	163.89	51.64	42.79
1.10	246.50	172.06	55.30	46.43
1.20	249.67	173.42	57.58	50.07
1.30	257.84	176.15	59.41	50.53
1.40	260.57	185.68	60.32	50.98
1.50	266.92	191.13	61.24	50.98
1.60	275.55	194.31	64.89	51.44
1.70	284.17	200.66	67.64	54.17
1.80	285.99	205.66	68.55	56.90
1.90	293.25	209.74	69.01	59.17
2.00	296.43	216.55	69.46	60.08

Table A.2 1, Continued. Consolidated data for Douglas-fir sonic test at 0.55 MPa.

.	Sonic	Hydr.	Sonic	Hydr.
File	820403A	820404A	820405A	820406A
Dry wt. (kg.)	0.3390	0.3480	0.3510	0.3310
Wet wt. (kg.)	0.3910	0.3975	0.4185	0.3645
Volume (m3)	7.0E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3	74.41	70.85	96.68	47.87
Abs. vol. kg/m3	61.65	53.90	92.80	36.94
Diff. %	17.15	23.92	4.02	22.83
Time (hr.) 0	.000.00	0.00	0.00	0.00
0.05	19.64	21.93	36.11	18.24
0.10	23.75	26.95	41.60	23.26
0.15	25.12	26.95	45.26	24.63
0.20	26.03	27.41	45.71	25.08
0.25	26.03	27.41	48.00	25.08
0.30	27.40	28.32	53.03	25.54
0.35	30.14	29.69	54.86	25.54
0.40	33.34	31.97	57.14	25.54
0.45	34.25	34.26	61.26	26.00
0.50	34.25	36.09	63.08	26.00
0.60	34.71	36.54	64.46	26.91
0.70	38.36	37.00	64.91	28.73
0.80	42.02	37.91	71.31	31.47
0.90	43.39	39.74	73.14	32.84
1.00	43.39	42.94	74.97	34.20
1.10	44.30	44.76	80.46	34.20
1.20	46.13	45.22	82.28	35.57
1.30	50.69	45.22	82.74	36.03
1.40	52.06	45.68	83.20	36.03
1.50	52.98	46.13	87.77	35.12
1.60	54.80	47.05	90.51	35.12
1.70	58.00	48.42	91.43	35.12
1.80	60.74	50.70	91.88	35.57
1.90	61.65	52.99	92.34	36.03
2.00	61.65	53.90	92.80	36.94

Table A.2.2 Consolidated data for Douglas-fir control group at 0.55 MPa.

File	800301B	800302B	800303B	800304B
Dry Wt. kg.	0.3360	0.3390	0.3380	0.3440
Wet wt. kg.	0.5095	0.5350	0.5570	0.5790
Volume m3	7.0E-04	7.0E-04	7.1E-04	7.0E-04
Abs. wt. kg/m3	246.50	278.26	309.32	334.14
Abs. vol. kg/m3	205.86	241.50	264.15	288.60
Diff. %	16.49	13.21	14.60	13.63
Time(hour) 0.00	0.00	0.00	0.00	0.00
0.05	47.61	57.09	55.44	72.60
0.10	59.85	72.49	72.57	95.75
0.15	68.01	81.10	87.90	106.64
0.20	75.72	91.07	97.82	117.98
0.25	80.71	99.68	107.28	126.60
0.30	87.06	102.40	112.69	134.77
0.35	87.97	108.74	118.55	143.85
0.40	96.13	112.82	126.66	152.47
0.45	97.94	118.71	134.33	159.28
0.50	105.20	126.87	139.29	166.54
0.60	107.01	130.04	144.69	171.07
0.70	115.17	140.91	155.06	180.60
0.80	124.24	153.14	164.53	196.49
0.90	132.85	161.30	179.40	206.02
1.00	141.02	166.74	188.42	214.64
1.10	146.00	173.99	192.48	225.07
1.20	151.44	181.69	206.00	234.15
1.30	160.06	190.75	210.05	241.86
1.40	164.14	199.81	218.17	250.03
1.50	171.85	204.80	226.28	253.66
1.60	178.65	210.23	234.85	262.28
1.70	187.27	218.39	243.41	270.00
1.80	188.17	226.09	246.12	273.63
1.90	197.24	228.81	254.23	279.53
2.00	205.40	236.51	262.34	287.70

Table A.2.2, Continued. Consolidated data fo Douglas-fir control group at 0.55 MPa.

File	800305B	800306B	800307B	800308B
Dry Wt. kg.	0.3455	0.3495	0.3500	0.3575
Wet wt. kg.	0.5070	0.5155	0.5010	0.4965
Volume m3	7.1E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3	227.63	236.71	215.25	198.21
Abs. vol. kg/m3	192.53	191.59	179.25	163.38
Diff. %	15.42	19.06	16.73	17.57
Time(hour) 0.00	0.00	0.00	0.00	0.00
0.05	54.43	51.42	55.05	53.24
0.10	66.57	61.44	64.60	62.80
0.15	75.57	70.08	72.79	70.99
0.20	80.07	78.73	81.43	79.18
0.25	86.37	85.56	85.98	81.92
0.30	93.56	88.29	90.99	89.20
0.35	97.61	95.57	93.72	90.56
0.40	103.01	97.39	99.63	91.93
0.45	103.46	101.48	100.54	97.84
0.50	109.31	106.03	102.82	99.21
0.60	112.46	106.94	108.73	100.57
0.70	121.00	115.14	111.01	108.31
0.80	128.20	122.87	120.11	114.68
0.90	131.35	125.15	127.38	116.96
1.00	139.00	133.79	130.57	122.42
1.10	146.19	142.44	136.48	126.97
1.20	148.89	146.08	142.40	134.25
1.30	156.54	152.00	145.58	136.53
1.40	158.34	160.19	147.40	143.81
1.50	166.44	161.55	154.23	144.72
1.60	173.18	169.75	155.59	145.17
1.70	175.43	171.11	162.87	151.09
1.80	182.18	179.30	164.69	153.82
1.90	184.43	187.04	171.97	158.37
2.00	188.03	188.40	174.70	162.92

Table A.2.2, Continued. Consolidated data for Douglas-fir control group at 0.55 MPa.

File	800309B	800310B	800311B	800312B
Dry Wt. kg.	0.3580	0.3500	0.3515	0.3465
Wet wt. kg.	0.5295	0.5685	0.5220	0.5080
Volume m3	7.1E-04	7.0E-04	7.1E-04	7.0E-04
Abs. wt. kg/m3	241.24	310.17	241.60	229.20
Abs. vol. kg/m3	205.16	265.03	209.38	195.67
Diff. %	14.96	14.55	13.33	14.63
Time(hour) 0.00	0.00	0.00	0.00	0.00
0.05	70.93	84.27	71.90	67.94
0.10	83.95	102.39	83.66	82.43
0.15	94.27	117.79	94.06	89.23
0.20	103.70	129.57	107.18	101.00
0.25	106.84	138.18	110.34	105.53
0.30	115.37	145.88	118.03	113.23
0.35	117.62	148.60	123.01	114.14
0.40	124.35	156.30	127.53	117.76
0.45	126.15	159.93	128.43	122.74
0.50	133.78	165.81	135.67	125.46
0.60	134.68	170.35	136.57	130.90
0.70	142.76	177.14	145.17	133.16
0.80	147.25	188.01	151.95	141.31
0.90	153.98	193.90	157.83	149.01
1.00	161.16	202.51	163.71	151.28
1.10	166.55	211.12	168.68	158.53
1.20	170.14	214.74	172.75	159.88
1.30	170.59	220.18	176.37	167.58
1.40	178.67	228.33	183.15	169.40
1.50	184.06	236.94	190.39	170.30
1.60	188.10	238.76	190.84	177.10
1.70	189.00	246.91	193.56	179.81
1.80	196.18	247.82	199.89	186.16
1.90	197.08	255.97	203.05	188.42
2.00	202.01	262.77	208.93	194.76

Table A.2.2, Continued. Consolidated data for Douglas-fir control group at 0.55 MPa.

File	800313B	800314b	800401B	800402B
Dry Wt. kg.	0.3485	0.3510	0.3355	0.3395
Wet wt. kg.	0.5505	0.5705	0.3850	0.3905
Volume m3	7.0E-04	7.0E-04	7.1E-04	7.0E-04
Abs. wt. kg/m3	286.79	313.47	70.08	72.34
Abs. vol. kg/m3	250.11	275.75	59.65	61.12
Diff. %	12.79	12.04	14.89	15.52
Time(hour) 0.00	0.00	0.00	0.00	0.00
0.05	61.62	73.38	23.04	19.47
0.10	90.17	99.36	23.50	23.54
0.15	106.48	117.13	23.95	24.90
0.20	119.17	127.62	28.92	25.80
0.25	125.96	139.01	30.73	25.80
0.30	133.21	147.22	31.18	27.16
0.35	141.37	154.96	32.08	29.88
0.40	144.54	163.17	32.08	33.05
0.45	150.88	171.83	32.53	33.95
0.50	158.13	174.56	33.44	33.95
0.60	160.85	181.86	35.24	34.41
0.70	169.01	191.43	39.76	35.31
0.80	178.98	201.00	40.67	40.29
0.90	186.68	209.20	41.12	42.56
1.00	187.58	218.32	42.02	43.01
1.10	195.74	227.43	43.38	43.46
1.20	202.08	232.45	46.54	44.37
1.30	206.16	237.00	49.70	47.54
1.40	213.86	244.75	50.16	50.70
1.50	222.47	246.58	51.06	52.06
1.60	223.38	254.32	52.87	52.06
1.70	231.99	256.15	55.58	55.68
1.80	232.90	263.90	58.74	59.31
1.90	240.60	270.73	59.19	60.66
2.00	246.94	273.47	59.19	61.12

Table A.2.2, Continued. Consolidated data for Douglas-fir control group at 0.55 MPa.

File		800403B	800404B	800405B	800406B
Dry Wt. kg.		0.3415	0.3390	0.3480	0.3450
Wet wt. kg.		0.3955	0.3845	0.4100	0.4060
Volume m3		7.0E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3		76.79	64.54	88.80	86.68
Abs. vol. kg/m3		67.62	53.42	73.59	69.84
Diff. %		11.94	17.23	17.13	19.43
Time(hour)	0.00	0.00	0.00	0.00	0.00
	0.05	22.69	21.73	15.08	15.42
	0.10	25.87	26.71	19.65	18.14
	0.15	29.95	26.71	24.68	24.49
	0.20	31.77	27.16	27.88	24.49
	0.25	32.22	27.16	28.80	28.12
	0.30	32.68	28.07	33.82	32.65
	0.35	35.85	29.43	36.57	33.11
	0.40	39.03	31.69	36.57	34.47
	0.45	40.85	33.95	37.02	37.64
	0.50	40.85	35.76	38.40	40.81
	0.60	40.85	35.76	44.34	42.18
	0.70	44.93	36.22	45.71	43.08
	0.80	49.02	36.67	46.17	47.62
	0.90	49.47	38.03	51.65	50.79
	1.00	49.92	41.20	54.85	51.70
	1.10	51.74	43.91	55.31	53.51
	1.20	56.28	44.82	56.22	58.95
	1.30	58.09	44.82	58.51	60.32
	1.40	58.55	45.27	63.08	60.77
	1.50	58.55	45.27	64.45	62.58
	1.60	58.55	46.18	65.36	67.12
	1.70	60.36	47.08	65.82	69.39
	1.80	63.09	48.89	69.48	69.84
	1.90	65.81	51.61	73.13	69.84
	2.00	67.17	53.42	73.59	69.84

Table A.2.3 Consolidated data for Douglas-fir sonic test at 0.69 MPa.

.	Sonic	Hydr.	Sonic	Hydr.
File	120101B	120102B	120103B	120104B
Dry wt. (kg.)	0.4045	0.4045	0.4045	0.4190
Wet wt. (kg.)	0.5770	0.5325	0.5665	0.5320
Volume (m3)	7.0E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3	246.07	182.72	232.17	160.97
Abs. vol. kg/m3	193.94	138.95	178.83	127.30
Diff. %	21.19	23.95	22.97	20.92
Time (hr.) 0	.000.00	0.00	0.00	0.00
0.05	37.33	55.12	23.33	45.46
0.10	55.54	66.51	33.85	50.92
0.15	66.92	75.17	56.26	55.01
0.20	81.04	83.37	71.81	60.92
0.25	89.69	85.19	83.24	65.01
0.30	91.96	91.57	89.19	69.10
0.35	100.61	92.94	94.68	70.01
0.40	101.52	94.30	102.91	71.38
0.45	109.26	99.77	105.20	77.29
0.50	114.27	102.05	112.52	7.56
0.60	122.01	105.69	121.21	86.83
0.70	128.84	110.70	127.15	88.20
0.80	136.12	11.62	130.35	93.65
0.90	145.68	115.26	134.93	97.29
1.00	148.41	120.27	140.87	98.20
1.10	156.15	121.18	148.65	104.56
1.20	159.80	122.09	150.93	106.38
1.30	165.26	125.74	157.34	106.38
1.40	171.63	129.38	158.25	109.11
1.50	174.36	129.84	160.08	115.02
1.60	180.74	130.75	166.94	116.84
1.70	183.47	133.94	171.06	121.84
1.80	183.47	137.13	176.09	124.11
1.90	188.93	138.49	177.01	125.48
2.00	193.94	138.49	178.83	127.30

Table A.2.3, Continued. Consolidated data for Douglas-fir sonic test at 0.69 MPa.

	Sonic	Hydr.	Sonic	Hydr.
File	120105B	120106b	120213A	120214A
Dry wt. (kg.)	0.4070	0.4005	0.3940	0.4105
Wet wt. (kg.)	0.5780	0.5065	0.5055	0.4830
Volume (m3)	7.0E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3	243.80	151.35	158.44	102.87
Abs. vol. kg/m3	177.45	92.50	146.45	86.35
Diff. %	27.21	38.88	7.57	16.06
Time (hr.) 0	.000.00	0.00	0.00	0.00
0.05	50.96	36.00	45.77	32.01
0.10	79.17	42.38	55.29	34.73
0.15	91.91	48.30	63.45	41.07
0.20	103.29	54.68	66.63	41.07
0.25	114.21	55.14	72.98	44.69
0.30	116.94	57.87	74.34	48.77
0.35	124.22	63.34	77.51	50.12
0.40	125.58	63.79	82.05	51.03
0.45	133.32	65.16	83.41	54.20
0.50	136.50	69.72	88.40	57.37
0.60	143.78	73.52	92.02	58.73
0.70	151.52	80.20	98.83	59.63
0.80	157.43	82.93	101.09	64.62
0.90	161.98	83.39	105.63	67.33
1.00	168.81	88.86	110.62	68.24
1.10	170.63	92.05	111.07	70.05
1.20	177.91	92.96	117.87	75.48
1.30	179.73	100.25	119.69	76.84
1.40	186.55	101.16	123.77	77.29
1.50	187.92	102.07	127.85	77.29
1.60	188.83	108.45	130.57	79.11
1.70	193.83	109.82	136.47	83.63
1.80	197.47	110.73	137.83	85.90
1.90	197.93	115.74	142.36	86.35
2.00	206.12	118.47	145.99	85.90

Table A.2.3, Continued. Consolidated data for Douglas-fir sonic test at 0.69 MPa.

	Sonic	Hydr.	Sonic	Hydr.
File	120202A	120201A	120204A	120203A
Dry wt. (kg.)	0.3685	0.3685	0.3605	0.3610
Wet wt. (kg.)	0.4180	0.4025	0.4000	0.3950
Volume (m3)	7.1E-04	7.1E-04	7.1E-04	7.0E-04
Abs. wt. kg/m3	70.07	48.10	55.97	48.25
Abs. vol. kg/m3	62.40	42.44	46.65	34.40
Diff. %	10.94	11.77	16.65	28.71
Time (hr.) 0.00	0.00	0.00	0.00	0.00
0.05	9.09	19.41	18.16	16.28
0.10	16.32	21.22	18.16	16.73
0.15	16.32	21.67	18.61	17.64
0.20	16.77	22.12	19.52	19.90
0.25	17.68	22.57	22.23	22.17
0.30	20.39	23.49	24.49	24.43
0.35	24.00	24.83	25.85	25.34
0.40	25.36	28.44	26.75	25.34
0.45	25.36	29.80	27.21	25.34
0.50	26.26	30.70	27.66	25.34
0.60	30.78	31.15	28.56	25.79
0.70	34.39	31.15	29.47	26.24
0.80	34.39	31.60	33.08	28.06
0.90	38.01	32.05	36.25	30.77
1.00	42.52	35.67	36.70	33.04
1.10	44.33	37.92	36.70	33.94
1.20	49.75	39.28	37.15	34.40
1.30	52.01	40.18	38.96	34.40
1.40	52.46	40.18	42.13	34.40
1.50	52.91	40.18	44.39	34.85
1.60	55.17	40.63	45.29	34.85
1.70	59.24	40.63	45.75	34.85
1.80	61.05	40.63	45.75	35.75
1.90	61.95	41.53	45.75	36.21
2.00	62.40	42.44	46.65	37.57

Table A.2.3, Continued. Consolidated data for Douglas-fir sonic test at 0.69 MPa.

	Sonic	Hydr.	Sonic	Hydr.
File	120206A	120205A	120207a	120208A
Dry wt. (kg.)	0.3650	0.3660	0.3645	0.3650
Wet wt. (kg.)	0.4170	0.4045	0.4105	0.3975
Volume (m3)	7.3E-04	7.1E-04	7.0E-04	7.1E-04
Abs. wt. kg/m3	71.47	54.56	65.31	45.98
Abs. vol. kg/m3	58.83	43.04	50.29	32.79
Diff. %	17.69	21.12	22.99	28.68
Time (hr.) 0	.000.00	0.00	0.00	0.00
0.05	50.96	36.00	14.04	12.02
0.10	79.17	42.00	14.50	12.93
0.15	91.91	48.30	15.40	14.28
0.20	103.29	54.68	20.39	14.28
0.25	114.21	55.14	22.20	14.73
0.30	116.94	57.87	23.10	16.08
0.35	124.22	63.64	24.01	17.44
0.40	125.58	63.79	24.92	18.10
0.45	133.32	65.16	26.28	20.15
0.50	136.50	69.72	28.99	20.60
0.60	143.78	73.82	31.71	21.05
0.70	151.52	80.20	33.07	21.05
0.80	157.43	82.93	33.07	22.86
0.90	161.98	83.39	33.07	24.21
1.00	168.81	88.86	34.43	26.02
1.10	170.63	92.05	37.15	27.37
1.20	177.91	92.96	40.78	28.73
1.30	179.73	100.25	41.68	29.18
1.40	186.55	101.16	41.68	30.08
1.50	187.92	102.07	41.68	30.70
1.60	188.83	108.45	42.13	30.99
1.70	193.83	109.82	43.49	30.99
1.80	197.47	110.73	46.21	31.44
1.90	197.93	115.74	49.84	31.89
2.00	206.12	118.47	50.29	32.79

Table A.2.3, Continued. Consolidated data for Douglas-fir sonic test at 0.69 MPa.

.	Sonic	Hydr.	Sonic	Hydr.
File	120210A	120209A	120211a	120212a
Dry wt. (kg.)	0.3550	0.3520	0.3565	0.3795
Wet wt. (kg.)	0.4520	0.3895	0.4420	0.4545
Volume (m3)	7.0E-04	7.0E-04	7.1E-04	7.0E-04
Abs. wt. kg/m3	137.60	53.45	121.27	106.68
Abs. vol. kg/m3	119.73	40.23	97.19	86.19
Diff. %	12.98	24.74	19.85	19.20
Time (hr.) 0	.000.00	0.00	0.00	0.00
0.05	37.34	19.30	13.00	28.09
0.10	46.84	20.21	19.33	32.62
0.15	48.66	20.67	25.22	36.71
0.20	56.35	20.67	26.58	40.80
0.25	57.71	20.67	32.01	41.71
0.30	64.50	20.67	35.18	46.70
0.35	65.86	21.58	38.80	49.42
0.40	67.22	22.94	43.32	49.42
0.45	72.20	24.76	43.78	49.88
0.50	74.46	26.58	44.23	51.24
0.60	74.91	28.40	47.85	57.14
0.70	79.89	28.85	52.83	58.50
0.80	83.51	29.31	53.28	58.96
0.90	84.42	29.31	58.26	64.40
1.00	90.76	29.76	62.34	68.03
1.10	92.57	30.22	63.24	68.03
1.20	93.47	31.58	70.48	69.40
1.30	99.36	34.77	71.39	72.57
1.40	102.08	37.04	72.29	75.75
1.50	102.53	37.95	79.08	77.11
1.60	106.60	38.41	80.89	78.02
1.70	110.68	38.41	87.68	78.48
1.80	111.13	38.41	89.49	82.11
1.90	114.30	38.86	90.85	85.74
2.00	119.73	38.86	97.19	86.19

Table A.2.4 Consolidated data for Douglas-fir control group at 0.69 MPa.

File	100109B	100110B	100111B	100112B
Dry Wt. kg.	0.3975	0.4025	0.3990	0.4115
Wet wt. kg.	0.5005	0.5140	0.5085	0.5160
Volume m3	7.1E-04	7.0E-04	7.0E-04	7.1E-04
Abs. wt. kg/m3	145.93	158.33	155.54	148.14
Abs. vol. kg/m3	118.01	133.69	121.95	116.72
Diff. %	19.13	15.56	21.60	21.21
Time(hour) 0.00	0.00	0.00	0.00	0.00
0.05	45.22	44.86	45.33	39.81
0.10	54.26	53.47	53.49	44.79
0.15	61.95	61.63	55.76	49.31
0.20	63.30	62.54	63.47	53.84
0.25	67.37	69.34	64.83	55.19
0.30	71.89	70.70	65.74	61.53
0.35	71.89	71.60	71.63	62.89
0.40	73.25	77.04	73.90	64.69
0.45	76.42	79.76	74.35	70.12
0.50	80.94	82.02	80.70	71.93
0.60	81.84	88.82	82.51	72.39
0.70	82.29	89.73	85.23	77.81
0.80	88.17	97.43	90.67	81.43
0.90	90.43	98.34	91.58	83.24
1.00	91.79	99.70	96.11	89.58
1.10	97.67	104.68	100.19	90.48
1.20	99.48	107.86	100.19	92.29
1.30	100.38	112.39	101.10	98.17
1.40	104.90	116.01	105.18	99.53
1.50	107.61	116.92	109.71	100.89
1.60	108.52	119.18	111.52	107.22
1.70	109.88	125.53	116.96	108.58
1.80	114.40	125.98	118.32	109.03
1.90	117.56	127.34	118.78	113.10
2.00	118.01	133.69	121.95	116.72

Table A.2.4, Continued. Consolidated data for Douglas-fir control group at 0.69 MPa.

File		100113B	100114B	100201B	1200201B
Dry Wt. kg.		0.4100	0.4050	0.3455	0.3415
Wet wt. kg.		0.6385	0.5860	0.3790	0.3746
Volume m3		7.0E-04	7.0E-04	7.1E-04	7.1E-04
Abs. wt. kg/m3		324.24	257.09	47.31	46.92
Abs. vol. kg/m3		272.62	224.84	41.46	41.62
Diff. %		15.92	12.54	12.35	11.30
Time(hour)	0.00	0.00	0.00	0.00	0.00
	0.05	64.76	71.62	16.23	16.74
	0.10	88.76	84.32	20.73	17.64
	0.15	100.08	95.65	22.53	19.45
	0.20	115.93	107.89	22.53	22.62
	0.25	122.27	113.33	22.99	19.00
	0.30	128.16	118.77	22.99	21.26
	0.35	138.12	126.47	23.44	23.53
	0.40	146.27	127.83	23.89	24.43
	0.45	154.88	135.09	24.79	24.88
	0.50	159.86	136.90	26.59	25.34
	0.60	172.99	148.23	29.30	25.34
	0.70	182.05	154.58	31.10	25.79
	0.80	191.11	162.74	31.55	26.69
	0.90	200.16	165.91	32.00	29.41
	1.00	208.77	173.17	32.45	29.41
	1.10	218.28	181.33	33.35	32.12
	1.20	227.34	185.86	35.61	33.48
	1.30	235.94	190.39	37.41	33.93
	1.40	240.47	196.29	39.66	34.39
	1.50	245.45	199.46	40.11	33.93
	1.60	253.60	206.71	40.11	34.39
	1.70	255.41	209.43	40.56	35.29
	1.80	263.57	214.42	40.56	37.55
	1.90	271.26	218.04	41.01	39.81
	2.00	272.62	224.84	41.46	41.62

Table A.2.4, Continued. Consolidateed data for Douglas-fir control group at 0.69 MPa.

File	100203B	100204B	100205B	100206B
Dry Wt. kg.	0.3375	0.3295	0.3400	0.3420
Wet wt. kg.	0.3645	0.3615	0.3730	0.3775
Volume m3	7.1E-04	7.1E-04	7.1E-04	7.0E-04
Abs. wt. kg/m3	38.17	45.37	46.67	50.44
Abs. vol. kg/m3	30.68	36.66	36.56	43.54
Diff. %	19.62	19.22	21.66	13.70
Time(hour) 0.00	0.00	0.00	0.00	0.00
0.05	14.44	17.65	11.73	16.78
0.10	16.24	18.10	14.44	17.23
0.15	16.69	18.10	16.70	17.69
0.20	17.14	18.55	18.05	18.14
0.25	16.69	18.55	18.96	19.05
0.30	17.14	19.01	18.96	21.31
0.35	17.14	19.91	18.96	22.67
0.40	17.14	21.27	19.41	24.49
0.45	17.14	22.17	19.41	25.40
0.50	18.50	24.44	18.96	25.85
0.60	18.50	26.25	18.96	26.76
0.70	20.30	27.15	19.41	27.21
0.80	22.56	26.70	20.76	29.93
0.90	24.36	26.70	22.57	32.65
1.00	25.72	27.60	24.37	34.01
1.10	25.72	28.06	26.18	34.01
1.20	26.17	28.51	27.08	34.92
1.30	26.17	30.32	28.43	34.92
1.40	26.17	33.03	28.43	35.37
1.50	26.62	34.39	29.34	35.83
1.60	26.62	35.75	30.69	36.28
1.70	26.62	35.75	31.59	39.00
1.80	27.52	35.75	33.40	40.81
1.90	29.32	36.20	36.11	41.72
2.00	30.68	36.20	36.56	43.54

Table A.2.4, Continued. Consolidated data for Douglas-fir control group at 0.69 MPa.

File	100207B	100208B	100209B	100210B
Dry Wt. kg.	0.3425	0.3565	0.3550	0.3690
Wet wt. kg.	0.3860	0.4085	0.4270	0.4470
Volume m3	7.0E-04	7.0E-04	7.1E-04	7.1E-04
Abs. wt. kg/m3	61.87	73.90	102.07	110.25
Abs. vol. kg/m3	53.56	64.41	84.15	94.73
Diff. %	13.43	12.85	17.55	14.08
Time(hour) 0.00	0.00	0.00	0.00	0.00
0.05	23.60	27.21	29.86	31.13
0.10	24.51	27.67	36.19	35.19
0.15	24.96	29.48	36.65	36.09
0.20	25.42	33.56	37.10	37.89
0.25	29.96	35.38	40.27	42.40
0.30	32.23	36.29	42.98	44.21
0.35	33.14	36.29	44.79	46.01
0.40	33.14	36.74	45.69	50.52
0.45	33.59	37.19	47.96	52.78
0.50	33.59	39.46	52.03	54.13
0.60	34.04	44.00	54.29	55.03
0.70	34.50	45.36	54.74	61.35
0.80	35.40	45.36	58.81	63.15
0.90	38.13	46.26	63.34	64.06
1.00	42.21	47.17	63.79	65.86
1.10	43.58	51.71	63.79	71.27
1.20	43.58	53.97	66.05	71.72
1.30	47.66	54.43	71.48	73.08
1.40	50.38	54.88	72.39	79.84
1.50	51.75	55.79	73.74	80.75
1.60	51.75	58.96	79.17	81.20
1.70	51.75	62.14	81.44	83.90
1.80	51.75	63.95	81.44	89.32
1.90	52.20	63.95	81.89	91.12
2.00	53.56	63.95	84.15	94.73

Table A.2.4, Continued. Consolidated data for Douglas-fir control group at 0.69 MPa.

File	100211B	100212B	100213B	100214B
Dry Wt. kg.	0.3795	0.3965	0.3890	0.3975
Wet wt. kg.	0.4665	0.5170	0.4820	0.5085
Volume m3	7.0E-04	7.0E-04	7.0E-04	7.0E-04
Abs. wt. kg/m3	124.66	172.70	133.20	158.27
Abs. vol. kg/m3	91.46	128.98	109.24	128.32
Diff. %	26.63	25.31	17.98	18.92
Time(hour) 0.00	0.00	0.00	0.00	0.00
0.05	18.29	36.13	40.68	45.05
0.10	26.52	45.74	48.91	54.15
0.15	29.72	47.11	53.02	61.43
0.20	35.21	54.89	53.94	63.71
0.25	35.67	57.17	54.39	69.62
0.30	39.78	64.03	58.96	71.90
0.35	43.44	64.95	62.16	72.35
0.40	44.36	66.78	63.08	72.81
0.45	45.73	72.72	63.54	74.63
0.50	50.76	74.10	69.48	78.27
0.60	53.50	75.47	72.22	82.36
0.70	58.08	82.79	75.88	89.64
0.80	62.65	84.62	80.45	90.55
0.90	63.56	91.48	80.91	91.92
1.00	69.05	93.31	81.36	99.20
1.10	71.79	98.80	87.30	100.11
1.20	72.71	102.00	90.05	106.48
1.30	76.82	106.57	91.88	108.30
1.40	80.48	110.69	97.36	110.12
1.50	80.94	111.60	99.19	114.22
1.60	82.77	116.63	99.65	117.40
1.70	88.71	119.38	101.47	118.31
1.80	90.09	120.29	107.42	124.23
1.90	90.54	126.70	108.79	126.96
2.00	91.46	128.98	109.24	128.32