LONGITUDINAL PERMEABILITY WITHIN DOUGLAS-FIR (PSEUDOTSUGA MENZIESII (Mirb.) Franco) GROWTH INCREMENTS

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ABSTRACT

An apparatus was constructed to measure the longitudinal gas-permeability of wood microsections about 150 microns thick. This apparatus was used to examine low surface tension drying methods of wood (freeze-drying and alcohol-benzene extraction) believed to maintain the bordered pit tori of Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) in the non-aspirated condition. Results were compared with drying methods believed to aspirate tori (air-drying, oven-drying and boiling-under-vacuum). Dry nitrogen gas-permeability measurements were made under "steady state" conditions. Similar drying techniques were used to prepare gross specimens which were subsequently subjected to "non-steady state" pressure treatment in end-penetration. Sapwood and heartwood specimens from impermeable interior-type and permeable coast-type Douglas fir were tested.

With both gross sections and microsections, the two low surface tension drying methods provided more permeable wood than did air-drying. Boiling-under-vacuum was as effective as low surface tension methods in improving gas-permeability, but not creosote-permeability, whereas oven-drying was as effective as low surface tension methods in improving creosote-permeability, but not gas-permeability. The improvement was most striking in all sapwood samples, less in coast-type heartwood, and nil or not measurable in interior-type heartwood.

Under the experimental conditions, latewood gas-permeability was about 2 darcies for all specimens and drying methods. Heartwood early-wood gas-permeability ranged from 0.02 to 2 darcies but was unaffected by drying methods. Sapwood earlywood gas-permeability was improved from

8 to 30 times by low surface tension drying. The greatest gas-permeability was found in the first-formed earlywood, which ranged from 2 to 100 darcies. The later-formed earlywood ranged from 0.02 to 100 darcies, depending on wood origin and drying method.

Creosote-permeability of interior-type heartwood was uniformly low by all drying methods. Interior-type sapwood and coast-type sapwood and heartwood were much more permeable after low surface tension drying or oven-drying. By visual observations, after all drying methods, latewood was more permeable than earlywood.

Low surface tension drying methods improve earlywood gas-permeability of sapwood, and latewood creosote-permeability of sapwood and coast-type heartwood.

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INTRODUCTION

The manner in which liquids and gases penetrate into coniferous woods is of interest to wood scientists in the fields of wood preservation, pulping, fire retardants and, more recently, wood-plastic copolymers. Since investigations were begun in the first decade of this century, many aspects of wood penetration have been studied so that at the present time a considerable amount of information has been collected. In spite of this, however, there are still areas of doubt as to some details of the penetration mechanism. It is the purpose of this study to investigate certain of these.

LITERATURE SURVEY

Penetration Through Spiral Checks

Tiemann (25) observed that under some conditions, spiral checks appear in wood cell walls, and he presumed that the passage of liquids from one tracheid to the next took place through these checks. Weiss (26) amplified this theory by proposing that the higher permeability of latewood was attributable to its greater tendency to check due to the stiffer nature of its cell walls.

Gerry (11) did not find evidence that the spiral slits of loblolly pine (*Pinus taeda* L.) assisted penetration. Bailey (1) in a microscopic study of Sequoia (*Sequoia* spp.) and longleaf pine (*Pinus palustris* Mill.) woods showed that while spiral checks were sometimes observed, they penetrated only the tertiary and secondary walls, whereas the primary wall remained intact and presumably resisted passage of fluids.

Penetration Through Resin Canals and Wood Rays

Gerry (11) investigated the function of horizontal resin canals and ray cells in the penetration of loblolly pine wood, and considered that their participation had been overestimated. She found that ray cells in the latewood appeared to be penetrated by creosote only after the adjacent tracheids were full. The horizontal resin canals were found to contain resin, which was not dissolved by the creosote even when adjacent tracheids were penetrated. Penetration of the earlywood, which might be expected to receive creosote from adjacent resin canals was found to be extremely slow.

Teesdale (24), after penetration studies on several woods, concluded that, while horizontal resin canals were responsible for treatability of some species, they were not a significant factor in others.

Erickson (9) forced water through tangential specimens of loblolly pine, longleaf pine, shortleaf pine (P. echinata Mill.), Douglas fir (Pseudotsuga menziesii (Mirb.) Franco), and tamarack (Larix laricina (Du Roi) K. Koch) 1.25 mm. thick, and demonstrated that horizontal resin canals in some cases conducted water. Permeability of the resin canals, however, varied greatly both with species and within individual specimens.

Buro and Buro (5) found no correlation between the concentration of resin canals and the longitudinal gas permeability of 7 mm. cubes of pine (Pinus spp.). It appears, therefore, that resin canals vary in their effect on permeability between species and even between specimens.

Above all, resin canals alone do not explain penetration effects, since woods not having normal resiniferous systems also display variable penetration behaviour.

Penetration Through Bordered Pits

Bailey (2) demonstrated by the use of carbon particles in suspension that liquids penetrate from tracheid to tracheid by way of bordered pits, and proposed that the formation of gas-liquid menisci in the minute openings of the pit membrane prevents penetration of gases. While communication through the bordered pit pairs has been questioned from time to time (11, 23) it has generally been accepted by wood scientists.

Effect of Pit Aspiration on Penetration

Bailey (2) likened the torus of a coniferous bordered pit pair in the living tree to a valve which resists penetration of gases. Extending the concept that gas-liquid menisci in the openings of the pit membrane resist gas movement, he proposed that additional pressure applied on the gas moved the torus to cover one or the other pit opening, effectively sealing the pit. Griffin (12, 13) showed that, while atmospheric air pressure alone is not sufficient to displace the torus, air-dried Douglas fir generally contains a higher proportion of aspirated pits than does unseasoned material. Phillips (20), in studies on Austrian pine (Pinus nigra var. calabrica), noted a gradually increased number of aspirated pits as the wood dried from the green condition to about 30% moisture content, at which time the majority of the pits became aspirated. Erickson and Crawford (7), in studies on Douglas fir and western hemlock

(*Tsuga heterophylla* (Raf.) Sarg.), noted similar aspiration of bordered pits during drying.

Although the aspiration of bordered pit tori is generally believed to prevent the penetration of fluids, this is not unanimously accepted. Bailey (2) considered aspiration as preventing penetration, and Griffin (12) provided evidence to support the theory, particularly as it applies to mountain-type Douglas fir. Stone (23), however, examined 10,000 tori in treated and untreated coast-type Douglas fir wood and concluded that in spite of the fact that most tori were aspirated the wood was still permeable. He concluded further that the lining of the bordered pit was too rough to give a tight seal.

Effect of Drying from Organic Solvents on Pit Aspiration

Bailey (2) suggested surface tension of water as the functional agent in aspiration of coniferous pit tori. Although Liese and Bauch (18) formally demonstrated that a surface tension of the evaporating liquid in excess of about 26 dyne/cm. is sufficient to effect pit aspiration in Scots pine (*Pinus sylvestris* L.), and that liquids with a surface tension below this value do not aspirate the torus, Griffin (12) had anticipated these results. She demonstrated that soaking green wood in alcohol (surface tension 22.3 dynes/cm. at 20°C) and subsequent drying left the torus in the central position. Stone (23), however, reported that soaking in alcohol did not prevent the majority of pits from being aspirated. More recently Furusawa (10) and Erickson and Crawford (7) confirmed Griffin's conclusions.

Effect of Solvent-Drying on Permeability

In spite of the fact that Griffin demonstrated the effect of solvent-drying on aspiration, and indirectly suggested the effect on permeability, Erickson and Crawford (7) appear to have been the first to test the relationship between permeability and pit aspiration by determining the permeability of solvent-dried wood. In their experiments they measured the longitudinal water-permeability of green Douglas fir and western hemlock. Results were compared among matched specimens, some of which were air-dried and others solvent-dried from alcohol, alcohol-benzene and acetone. Whereas air-drying reduced the water-permeability of green Douglas fir wood to one to two per cent and western hemlock to two to four per cent of their respective green values, the water-permeability of solvent-dried Douglas fir was 70 to 103 per cent and western hemlock 110 to 115 per cent of green values. Based on microscopic observations, they attributed the improved permeability of solvent-dried wood to the fact that the tori of bordered pits were not aspirated.

Clermont and McKnight (6) subjected Douglas fir, red pine (*Pinus resinosa* Ait.) and white spruce (*Picea glauca* (Moench) Voss) woods to various drying treatments -- air-drying, oven-drying, and solvent-drying -- followed by measuring nitrogen-permeability in the axial direction. Sapwood samples were about one hundred times more permeable than corresponding heartwoods. In general, solvent-dried samples were more permeable than air-dried samples. However, heartwood samples from Douglas fir and white spruce were not affected by the seasoning treatments.

Krahmer and Cote (16) reported that the increased permeability of alcohol-dried wood was not caused by extractive removal. In performing a control for their experiment they soaked the sapwoods of Douglas fir, western hemlock and western redcedar (_Thuja plicata_ Donn) in alcohol, then in water, and permitted the woods to dry from the water-wet condition. No improvement in permeability resulted when this drying sequence was used.

Earlywood _vs_. Latewood Permeabiltity

Weiss (26) appears to have been the first to record the observation that latewood is more readily penetrated in the axial direction than earlywood. This has been confirmed by many investigators since that time, and has been a constant consideration in theories on wood permeability. Weiss (26) explained the phenonemon on the basis that spiral checks in tracheid walls were responsible for communication from lumen to lumen. Griffin (12) confirmed the observation, but explained the effect on the basis of aspiration of bordered pits. Other investigators, including Erickson, Schmitz and Gortner (8), Furusawa (10), Harris (15), Koljo (17), Scarth (21) and Teesdale (24) have noted also the higher permeability of latewood.

Investigators are not unanimous in recognizing higher permeability for latewood. Scarth (21), Buckman (4) and Teesdale (24) recorded cases where earlywood had a higher permeability. Teesdale (24) found that in most species the latewood and, in particular, the last formed tracheids which have the thickest walls and the smallest lumens, is penetrated first. However, in redwood (_Sequoia sempervirens_ (D. Donn) Endl.), tamarack and yew (<u>Taxus brevifolia</u> Nutt.), this generalization did not hold. In redwood the earlywood was the most easily treated, the summerwood being scarcely treated at all, whereas in tamarack and yew, both zones were similarly penetrated. Buckman (4), in study of southern yellow pine (<u>Pinus</u> spp.), found that in spite of the apparently higher concentration of cresote in the latewood, there was actually a higher concentration in the earlywood. Guillemain-Gouvernel (14), impregnated Jerusalem pine (<u>Pinus halepensis</u> Mill.) and Scots pine with pentachlorophenol dissolved in benzene, and found by analysis that Scots pine contained a significantly higher concentration in the latewood, whereas in Jerusalem pine the concentration in the two zones was not significantly different.

While these casual observations have been made for the last fifty years, only recently has a formal attempt been made to measure relative permeabilities of earlywood and latewood. No doubt this is because of difficult experimental problems associated with making such measurements.

Buro and Buro (5) attempted to partition the axial gas-permeability of small blocks of pine into earlywood and latewood components by sealing exposed earlywood on the ends of blocks with paraffin. They found considerable variation in their results. In some specimens, latewood permeability was low and fairly constant, whereas earlywood permeability ranged from high in the sapwood to low in the corewood. In other specimens, permeability was equal in adjacent earlywood and latewood ranging from high in the sapwood to low in the corewood. In still other specimens, the permeability of both zones was equal and constantly low.

Osnach (19) compared longitudinal gas-permeabilities of seven deciduous and four coniferous woods, and also partitioned the permeability of the faster growing species, poplar and pine (not identified as to species) into earlywood and latewood components. In the partition experiments, two types of specimen were used:

1. Specimens 20 mm. long and 2 to 3 mm. thick, consisting entirely of the growth zone portion being measured, and
2. Gross specimens with resin applied selectively on the cross-sections to isolate earlywood and latewood zones.

He obtained consistent results by both methods. In Canadian poplar sapwood, the earlywood was found to be 2.8 times more permeable than the latewood. In poplar heartwood this ratio was 4.9. The opposite relationship was noted for pine, for which sapwood latewood was 5.5 times more permeable than the corresponding earlywood. In heartwood the ratio was 7.6.

In the investigations reported by Buro and Buro (5) and by Osnach (19), no information was provided on wood seasoning methods. Presumably, these investigators dried their specimens from the green condition to the moisture content at which measurements were made without special seasoning techniques.

OBJECTIVES

The purpose of this study was to construct axial gas-permeability profiles within coniferous growth zones in examination of the hypothesis that important variations in permeability occur at this level of wood organization, and that these variations are reflected in creosote-permeability of whole wood. The hypothesis that wood permeability is seriously reduced during drying as a result of surface tension phenomena was also examined.

Since methods were not available for making gas-permeability measurements at the level desired, it was necessary to develop new techniques for examining minute wood specimens.

DEVELOPMENT OF APPARATUS

The gas-permeability apparatus was constructed as detailed in Fig. 1, and as pictured in Fig. 2. In principle, dry nitrogen is passed through the specimen at a pressure differential measured by a manometer, and its volume is measured by water displacement in a calibrated pipette. Five interchangeable pipettes, 0.2, 1, 3, 10 and 50 ml. capacity were constructed to conveniently measure a wide range of permeabilities.

The permeability cell (Fig. 1 and 3) was constructed to accept specimens of the order of 150 microns thick, about 8 mm. wide and 25 mm. long. The specimen is placed in jaws constructed to fit snugly over its ends without bearing on it. These jaws are connected to air inlet and outlet tubes, and the entire assembly of tubes, jaws and specimen is placed between two rubber sheets which separate the upper and lower parts of the hollow permeability cell. After bolting the cell together with the rubber sheets acting as gaskets, compressed air is admitted into upper and lower cavities of the cell to force the rubber into intimate contact with the microsection in order to prevent leakage around the specimen face from inlet to outlet.

Leakage around the specimen was the source of most problems encountered. At first, leakage was detected by replacing the microsection by a piece of brass shim of the same dimensions. It was found that when 40 psi pressure was used to force the rubber into contact with the brass shim, leakage still occurred for two reasons:

1. The rubber did not conform perfectly to the specimen, particularly along the edges, or
2. The rubber was sufficiently porous to permit detectable air-flow even when no differential pressure was applied across the specimen.

The use of a thick rubber reduced the second error, but increased the first, while the use of a thin rubber reversed the effect. Leakage around the brass shim blank was effectively prevented by the use of prophylactic rubber. While this material is very prone to damage when used alone, and is somewhat porous, when used in conjunction with thin dental rubber it did provide a perfect seal. In use, the dental rubber is placed adjacent to the metal cell, and the prophylactic rubber next to the specimen.

The use of pressuresvarying from 40 to 80 psi, to force the rubber into contact with wood microsections resulted in widely different gas flow readings. In fact, early experiments gave a high correlation between void volume of the wood and gas-flow for most of the determinations made under these conditions, suggesting that the greater part of the gas flow was taking place in the open, surface tracheids and minor cutting irregularities.

It was found that by placing cellulose adhesive tape on both sides of the specimen, and maintaining 80 psi pressure on the specimen for about an hour, consistent gas flow readings could be made when the compression pressure within the cell was in the range of 40 to 80 psi. Photomicrographs of microsection cross-sections prepared in this way showed the surface tracheids to be completely filled with the adhesive, whereas specimens similarly prepared but with pressure applied for only a few minutes had many surface tracheids incompletely filled (Fig. 4). Gas-flow determinations with these latter specimens at different compression pressures showed small but significant differences, supporting the hypothesis that, in previous experiments, the rubber was an imperfect seal for wood specimens. No specimens showed evidence of adhesive penetration beyond surface cavities.

In addition to the gas-permeability apparatus, two other pieces of equipment were constructed. The first was an apparatus for boiling micro- and gross specimens under vacuum as diagrammed in Fig. 5, and shown by photograph (Fig. 6). Specimens are placed in the retort containing a steam coil to supply heat, and are held down by means of metal bars. After closing the retort by placing a glass plate over the opening, xylene was added to cover the specimens. Connection to a Dean-Stark water-trap and condenser was made through a tapered metal female and standard 24/40 ground-glass male joint. Extra condensate collection capacity was obtained by connecting an Erlenmeyer flask into the system. The entire unit was operated at a vacuum of 20-in. mercury.

The third apparatus (Fig. 7) was a pressure retort for treating gross specimens. This was constructed of a piece of 2-in. steel pipe laid horizontally, and a vertical 3/4-in. pipe equipped with a boiler gauge glass. The retort was of a size to allow pressure-impregnation of one 1 x 1 x 12-in. specimen at a time. The gauge glass was pre-calibrated to read in grams of creosote. Air pressure applied above the liquid level in the standing pipe was used to impregnate the specimen, while readings of liquid level with time provided a measure of absorption rate.

EXPERIMENTAL

Selection of Gross Specimens

The gross specimens used for this study were selected to give a wide range of permeability, and to provide material for satisfactory preparation of matched microsections.

In a previous study, Bramhall (3) compared the permeability to creosote oil of Douglas fir from various provenances in British Columbia, and confirmed previous knowledge that the heartwood of specimens grown east of the Coast Range is quite impermeable, whereas the heartwood of specimens from the coastal region is usually relatively permeable. A relationship was noted also with annual precipitation in that areas of high rainfall produced permeable heartwood, whereas dry areas produced more impermeable heartwood. Sapwoods, though considerably more permeable than the corresponding heartwoods of each region, appeared to be influenced by the same factors.

Stem sections of freshly-felled Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees from Prince George, Haney, and Lake Cowichan, B.C. were obtained. Prince George, which is near the northern limit of the Douglas fir range in the B.C. interior, produces typically impermeable heartwood. Haney, in the lower Fraser Valley, is in a high rainfall area of the coastal region, and produces moderately permeable heartwood and permeable sapwood. Lake Cowichan is centrally located in the southern part of Vancouver Island. The permeability of Douglas fir from this area appears to vary widely, depending on the annual rainfall at the specific locality of growth.

In addition to geographic variation, stem sections were also selected to provide acceptable microsections, and gross sapwood specimens of suitable width. For this purpose such characteristics as: sapwood zone at least $1\frac{1}{4}$-in. wide, rate of growth 8 to 18 rings per in., straight grain, and diameter 15 to 20 in. inside the bark were chosen. Sections were cut 3-ft. long. Characteristics of specimens used in the study are given in Table 1.

Handling and Cutting of Gross Specimens

On arrival at the laboratory, the wood specimen blocks were stored in a controlled temperature -- humidity room at 35°F and 100 per cent relative humidity until they were removed for cutting. Gross specimens were cut to provide at least seven 1 x 1 x 14-in. specimens from each heartwood and sapwood. Sapwood specimens were cut on three sides parallel to the grain. The fourth, cambial side was left uncut, with only the bark removed. Heartwood specimens were cut adjacent to the sapwood-heartwood boundary. After cutting, specimens were returned to the humidity room until required.

Drying Techniques

Gross sapwood and heartwood specimens from each geographic area were dried according to each of the following five techniques:

1. Air-dried at room temperature to constant weight,
2. Oven-dried at 70°C to constant weight,
3. Freeze-dried at 50 microns mercury absolute pressure to constant weight,
4. Solvent-dried by Soxhlet extraction with 1:2 ethanol : benzene, for one week, during which 4 changes of solvent were made, followed by air-drying to constant weight, and
5. Boiling-under-vacuum in xylene at 20-in. mercury (about 250 mm mercury absolute pressure) until no more water could be removed, then air-dried to constant weight.

After seasoning, gross specimens were stored in a desiccator over "Drierite", anhydrous calcium sulphate, until required.

Creosote-Impregnation of Gross Specimens

After drying, the gross specimens were coated on four sides with two coats of clear epoxy resin in order to limit subsequent creosote penetration to the end surfaces. After polymerization of the resin, both ends of the specimens were trimmed to provide fresh surfaces. Length was reduced to a uniform 10-in. The specimens were then stored in a desiccator until required for impregnation with creosote in the apparatus (Fig. 7) described on p. 12. Each sample was weighed, following which it was placed in the lower 2-in. diameter pipe, which was then sealed with a plug. Creosote was introduced into the vertical pipe until it reached the zero mark on the calibrated boiler glass. A pressure gauge was screwed into the inlet. Air pressure at 80 psi was applied, and absorption readings versus time were recorded.

It was noted that, on application of pressure, the level in the boiler glass immediately fell 5 grams but this value was subsequently recovered on release of pressure. This is attributed to expansion of the equipment and compression of the wood under pressure. Pressure was applied until the specimens had absorbed 45 grams of creosote or for a period of three hours, whichever came first. After impregnation, the retort was drained, and the specimen was removed, cleaned and weighed. Treated specimens were then stored at -20°C until all impregnations were complete. They were then thawed, allowed to bleed, and split by saw in the radial plane to permit examination of earlywood-latewood penetration. The exposed surfaces were coated with lacquer to prevent surface-bleeding. In all, thirty specimens were treated as described.

Gas-Permeability of Microsections

Gross specimens for microsectioning were chosen to represent a wide range of permeabilities as determined by creosote-impregnation of air-dried specimens (Treatment 1). The specimens selected were sapwood and heartwood from both Prince George and Haney, B.C. No material from Lake Cowichan was used for this phase of the investigation. Of the gross specimens previously described, one from each area with straight grain in both axial and tangential directions had been set aside for microsectioning.

These four specimen blocks, 1 x 1 x $3\frac{1}{2}$-in. long, were saturated with water by soaking under vacuum until they sank, followed by applying pressure at 80 psi. Specimen blocks were then carefully aligned in the microtome to provide sections parallel with the grain, and serial tangential microsections of at least three consecutive growth increments were collected. Section thickness was about 150 microns. The sections were maintained saturated at all times.

Each microsection blank was cut into six pieces $\frac{1}{2}$ x 1-in. long, each suitably identified and randomly placed into a separate group. In this way six matched groups were formed from the original microsections. Five of the groups, randomly selected, were dried by one each of the five drying techniques already described for gross specimens (Treatments 1 to 5), and the sixth was retained as a spare. After treatment each microsection of a group was weighed, and the results were used to plot an approximate specific gravity profile across the annual rings being examined.

It is recognized that because of variation in individual specimen volumes, these results were only approximations, but they were sufficiently accurate for the purpose intended.

Eight micro-specimen blanks, equally spaced along the specific gravity profile of one annual increment, and two micro-specimen blanks, one earlywood and one latewood from next later growth increment, were designated for permeability measurements. The micro-specimen blanks were transferred to a large dry-box where the designated sections were selected from each group. One edge was torn from each specimen blank to establish grain direction, and specimens were cut to a standard width of 8.6 mm. by means of a cutting die mounted in an Arbor press. While still in the dry-box, the thicknesses were measured to the closest micron and recorded. Specimens were then transferred to another dry-box containing a Cahn electro-balance where their oven-dry weights were measured to 0.01 milligram.

Some minor discrepancies had been noted in the cutting of specimens to a standard width. Specimens were therefore measured as to both length and width on a travelling stage microscope, and returned to the desiccator for storage.

Cellulose-adhesive tape was applied to both sides of specimens to cover them for 23 mm.of their total length of 25 mm. They were then pressed between rubber sheets at 80 psi for three hours to cause exact conformity with specimen surface irregularities.

The specimens were placed in the permeability cell in the manner that has been described, and a cell pressure of 80 psi was applied to complete the seal and prevent leakage.

Depending on permeability of the individual specimen under test, either the 1 ml. or 10 ml. pipette was used. Extremely permeable or extremely impermeable specimens were tested at gas flow pressures of 3 and 60 cm. mercury (0.6 and 12 psi), respectively, while specimens of intermediate permeability were tested at an intermediate pressure. The objective was to maintain a fairly uniform, reasonable test time, which was usually between one and five minutes.

Replicate determinations in which the specimen remained in place in the permeability cell gave reproducibility within two per cent. No significant increase in error was noted when the specimen was removed from and replaced in the cell between determinations. Since the variation between adjacent microsections of similar specific gravity was usually several times this value, only two determinations of permeability without removal from the cell were made on all specimens. Two hundred microsections were tested in all.

Gas-permeability data and calculations are recorded in Table 2. Specific gravity, G, was calculated using the equation:

$$G = \frac{1000 \text{ x wt}}{L \text{ x } W \text{ x } T}$$

where: L = length, oven-dry (mm.) W = width, oven-dry (mm.)
T = thickness, oven-dry (microns) wt= weight, oven-dry (grams)

Permeability is defined as $\frac{\eta LV}{Apt}$ where volume V of a fluid of viscosity η passes through a specimen of length L and cross-sectional area A in time t under a pressure differential p. In this investigation longitudinal gas permeability P, in darcies (cp. ml./cm. atm.sec.) was calculated from the equation:

$$P = \frac{1.52 \times 10^5 x V x L}{T \times W \times p \times t}$$

where:

L = length (mm.)
p = pressure (mm. mercury)
T = nominal thickness (microns)(see Fig.4)
t = time (sec.)
V = volume of gas (ml.)
W = width (mm.)

and the viscosity η(0.02 for nitrogen at 20°C) is included in the constant.

RESULTS AND DISCUSSION

Specific gravities and the corresponding permeabilities are plotted against position within growth increments in Fig. 8 to 11 for each method of drying for interior-and coast-type Douglas fir sapwood and heartwood. Because of the natural curvature of the growth increment, the various test specimens cut from the same microsection blank did not come from exactly the same position within the increment. Points on the graph, therefore, were adjusted laterally to correspond to the appropriate point on the common specific gravity profile.

Effect of Wood Zone and Provenance on Permeability

It will be noted that the four graphs (Fig. 8 to 11) representing permeability of interior and coastal sapwood and heartwood, illustrate quite different permeability profiles, and that, with the exception of interior sapwood these patterns were not much changed by any of the drying methods used. All have in common a latewood permeability of about 2 darcies. Earlywood permeability varied over a wide range, however, depending on provenance and wood zone tested. Gas-permeability was lowest in the earlywood of interior Douglas fir heartwood, with values of about 0.02 darcy.

These values were too low to be measured accurately because of experimental errors introduced at this level. Interior sapwood earlywood was more permeable, with a wide range of values from 0.2 to 20 darcies. Coastal heartwood earlywood permeability was more uniform with values near 2 darcies, and coastal sapwood earlywood was the most permeable with values from 12 to 120 darcies.

Effect of Position within Increment on Gas-Permeability

While the gas-permeability has been shown to differ between earlywood and latewood, its profile symmetry did not always correspond with that of the specific gravity profile. The permeability profiles of Haney sapwood are symmetrical about the specific gravity profile (Fig. 10) and, as a result, a regression of permeability versus specific gravity is highly significant (Table 3). The permeability profiles of Haney heartwood are also symmetrical, because they are uniform across the growth increment (Fig. 11), but not all regressions are significant.

The permeability profiles of interior heartwood are strikingly similar, uniform and symmetrical (Fig. 9). They are not symmetrical, however, about the specific gravity profile in that they are displaced to the right. The zone of greatest permeability was at the boundary between the latewood and first-formed earlywood, and in the first cells of the earlywood. As a result, regressions of gas-permeability versus specific gravity gave somewhat lower correlations for the interior heartwood sample (Table 3).

The permeability of interior sapwood appears to have interacted with drying treatment. In those specimens which were freeze-dried and solvent-dried, the zone of greatest permeability was again in the first-formed earlywood, while the maximum for specimens boiled-under-vacuum appeared at the earlywood-latewood boundary.

These results suggest that a simple correlation between specific gravity and longitudinal gas-permeability may be fortuitous, and that the point of greatest permeability within an increment is not that of greatest specific gravity. These results add support to evidence presented by Wu and Wilson (27) that the first-formed earlywood has characteristics similar to those of the last-formed latewood, and quite different from those usually associated with earlywood.

Effect of Drying Procedure on Gas-Permeability

Liese and Bauch (18) have shown with Scots pine that drying from a liquid having surface tension at more than 26 dynes per cm. aspirates the torus of bordered pits, whereas drying from a low surface tension liquid results in non-aspirated tori. The same effect might be expected from freeze-drying, where a high surface tension gas-liquid interface is completely avoided. Since fluid flow in wood is believed to pass through the bordered pits, it would be expected that freeze-dried or solvent-dried wood would be more permeable than similar air-dried or oven-dried wood. These expectations were realized in these experiments for both interior and coastal sapwood earlywoods.

Longitudinal gas-permeability of coastal sapwood earlywood was increased 3 to 10 times over its air-dried values by solvent- and freeze-drying, whereas the latewood was not significantly affected (Fig. 10). Interior sapwood earlywood permeability was even more strikingly affected, being increased by a factor of about 30, while again the latewood was not significantly affected (Fig. 8). However, the heartwood of neither Douglas fir type was much affected by drying procedure.

The results support the currently accepted belief that aspiration of the bordered pits significantly affects permeability.

While the action of solvent-drying in improving permeability might be interpreted as a removal of incrusting substances or extractives from the cells, a similar result by freeze-drying indicates that aspiration of the earlywood tori is the predominant factor responsible for poor permeability of some Douglas fir.

This confirms the findings of Sebastian, Cote and Skaar (22) who observed aspiration and incrustation of bordered pit membranes in white spruce. Aspirated and non-incrusted membranes were common in slightly permeable heartwood, and non-aspirated, partly incrusted membranes were found in permeable sapwood. This suggests that aspiration, and not incrustation, is the more important factor of the two.

In both interior and coastal Douglas fir sapwood, the latewood permeability does not appear to be significantly affected by the drying procedure. Furthermore, as has already been noted, the latewood permeability is quite uniform in interior and coastal sapwood and heartwood. This supports the view of Phillips (20), who suggested that the thicker membrane of latewood bordered pits is stiff enough to resist aspiration by a receding water meniscus. The earlywood bordered pit membrane, however, is considerably thinner, and will be aspirated by a receding water meniscus.

The results of boiling-under-vacuum in xylene were inconsistent. In drying interior sapwood by this method, the earlywood permeability was reduced to values similar to those of air-dried and oven-dried wood. On the other hand, in drying coastal sapwood by this method, the earlywood permeability remained as high as that of freeze-dried and solvent-dried material. The following explanation is suggested for this apparent anomaly. In freeze-drying and in solvent-drying the surface tension of the evaporating interface is zero and 20 dynes per cm., respectively. Both values could be less than the minimum required to aspirate the earlywood tori. In air-drying and oven-drying, the surface tension is near that of water, in the order of 60 to 73 dynes per cm. at the temperatures prevailing. In boiling-under-vacuum, air is removed from the wood, and direct contact between water and xylene may be expected at an interfacial tension of about 32 to 37 dynes per cm. It is suggested that the force exerted by a meniscus of this nature is enough to aspirate some tori, as for example, those of interior Douglas fir sapwood earlywood, but not sufficient to aspirate stiffer tori, as for example, those of coastal Douglas fir sapwood earlywood. The fact that variations in resistance to aspiration exist is supported by Phillips (20) who showed in his studies that British-grown Douglas fir latewood was 21% non-aspirated, whereas Canadian-grown Douglas fir latewood was 53% non-aspirated.

While sapwood earlywood appears to be affected considerably by low surface tension drying techniques, neither latewood nor heartwood of either type are affected. No significant changes were found in either the characteristic shape of heartwood permeability profiles, or in their absolute values. Furthermore, the changes in coastal sapwood earlywood permeability, being of the order of 3 to 10 times, were not as great as the differences between earlywood and latewood permeability, which were of the order of 8 to 20 times. Consequently, no great differences was found in the character of the profile.

In the case of interior sapwood earlywood, the differences resulting from low surface tension drying are greater than earlywood-latewood differences. Consequently the characteristic shape of the curve is inverted. Earlywood remains more permeable than latewood by this technique.

Effect of Provenance on Creosote-Permeability

The rates of creosote absorption through the ends of 1 x 1 x 10-in. specimens are shown in Table 4. Variation of Douglas fir creosote-permeability with provenance in British Columbia is well known, and is dependent not only on region, but also upon annual precipitation on the growth site (3). This provenance effect is shown in Fig. 12 to 16. It will be seen that for all drying methods the sapwood and heartwood permeability decreases almost invariably in the order of Haney, Cowichan and Prince George. These represent high and moderate rainfall B.C. coastal conditions and a B.C. interior environment. It also appears from these data that factors responsible for low permeability in the heartwood had their origin in the sapwood, since the order of decreasing permeability is the same for both wood zones.

Effect of Drying Method on Creosote-Permeability

Fig. 17 to 19 show the effect of drying methods on the creosote-permeability of Douglas fir.

Rate of creosote absorption by interior-type Douglas fir heartwood was unaffected by drying methods (Fig. 17). Heartwood of intermediate permeability from a moderate rainfall coast environment was affected to some degree (Fig. 18), and permeable heartwood from a high rainfall coastal environment was largely influenced by drying methods (Fig. 19). The results show that the two methods believed to reduce pit aspiration by low surface tension drying phenomena, i.e., solvent-drying and freeze-drying, were consistently effective in maintaining wood permeability. Surprisingly, oven-drying at 70°C was equally effective. Air-drying and boiling-under-vacuum were associated with reduced creosote-permeability.

While the more permeable specimens absorbed creosote at a faster rate than impermeable specimens, the pattern of penetration varied little (Fig. 20 - 22). Invariably, near the specimen ends both earlywood and latewood were thoroughly penetrated, whereas several inches from the ends only the latewood was penetrated. In several cases, Cowichan solvent-dried sapwood, Cowichan air-dried, freeze-dried and boiled-under-vacuum heartwood, Haney oven-dried sapwood and Haney air-dried heartwood, creosote was observed in the earlywood tracheids immediately adjacent to and on both sides of the latewood. Since all drying methods demonstrated this phenomenon, it appears to be unrelated to drying method. In a few cases, Cowichan boiled-under-vacuum sapwood, interior oven-dried and boiled-under-vacuum sapwood, and Haney solvent-dried heartwood, the penetration appeared to be similar in both earlywood and latewood.

Relationship between Gas- and Creosote-Permeability

It was shown in the gas-permeability studies that longitudinal latewood permeability was not influenced by drying method, but that in most cases earlywood permeability was substantially affected. It is seen that longitudinal creosote-permeability is also substantially affected by drying method. Consequently a correlation might be expected between longitudinal gas-permeability of the earlywood and whole wood creosote-permeability. This expectation was realized, and is expressed in the following equation:

$$\log Y = -1.233 + 0.34 \log X \quad (R = 0.74^{**},\ n = 20 \quad SEE = 0.39)$$

$$\text{or} \quad Y = 0.06\,X^{.34}$$

** significant at 0.01 level

where Y = creosote absorption (grams) after 20 min. pressure at 80 psi

X = gas-permeability (darcies) of earlywood at specific gravity 0.20.

Gas-permeability and creosote-permeability were both very high after solvent-drying and freeze-drying, the two drying methods believed to leave the bordered pit tori non-aspirated. Permeability to both fluids was seriously diminished by air-drying, which is believed to cause aspiration of the tori. However, opposite reactions were found to oven-drying, which left creosote-permeability of all specimens unimpaired, but diminished gas-permeability, and to boiling-under-vacuum which left Haney sapwood earlywood gas-permeability unimpaired, but reduced creosote-permeability. These reactions did not relate to visual examination of the treated specimens.

Considering only those drying methods which produced the same effects in gas- and creosote-permeability, it is seen that latewood gas-permeability is not affected by drying method, but that the earlywood is affected. In comparing the creosote-permeability of specimens dried by various methods, however, no significant change of earlywood penetration was observed; in all cases the latewood was more easily penetrated, and only the rate of penetration was affected. It appears, therefore, that maintaining the earlywood bordered pits in a non-aspirated condition improves latewood creosote-permeability, without significantly improving earlywood penetration. No explanation is offered for this phenomenon.

CONCLUSIONS

1. Low surface tension drying methods (freeze-drying and alcohol-benzene extraction) rendered Douglas fir more permeable in the axial direction to gases and creosote than similar air-dried wood. Boiling-under-vacuum was as effective as low surface tension methods in improving gas-permeability, but not creosote-permeability, whereas oven-drying was as effective as low surface tension methods in improving creosote-permeability, but not gas-permeability. The similar effects of freeze-drying and solvent-drying support the hypothesis that aspiration of pit tori causes reduced permeability of air-dried wood.

2. Improvement of both gas- and creosote-permeability with low surface tension drying was most striking in sapwood, less in coast-type heartwood, and nil in interior-type heartwood. This indicates, as has been observed by other investigators, that in green Douglas fir most sapwood tori are non-aspirated, whereas many tori in coast-type heartwood and most tori in interior-type heartwood are aspirated and the wood is impermeable. Low surface tension drying methods do not release tori which were aspirated in the green wood.

3. Under the experimental conditions, latewood gas-permeability was about .2 darcies for all specimens and drying methods. Heartwood earlywood gas-permeability ranged from 0.02 to 2 darcies but was unaffected by drying methods. Sapwood earlywood gas-permeability, from 0.4 to 10 darcies in air-dried specimens, was improved 8 to 30 times by low surface-tension drying. This supports the hypothesis that the stiffer latewood pit membranes offer more resistance to pit aspiration in drying than earlywood pit membranes.

4. The highest gas-permeability within the growth increment of interior-type Douglas fir was in the last-formed latewood and first-formed earlywood, indicating that the first-formed earlywood has permeability characteristics more related to latewood than earlywood.

5. Whereas low surface tension drying methods improved earlywood but not latewood gas-permeability, they appeared to improve

earlywood and latewood creosote-permeability proportionately, suggesting that non-aspiration of earlywood bordered pit tori directly affects the penetration of latewood.

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TABLE 1

Characteristics of Douglas fir stem sections used in gross- and micro-permeability studies

B.C. Source	Diameter, in.	Age, yr.	Age at Sapwood-Heartwood Boundary, yr.	Sapwood Thickness, in.	Origin of Test Specimen			
					Gross		Micro	
					Sap. Age, yr.	Ht. Age, yr.	Sap. Age, yr.	Ht. Age, yr.
Prince George	20.1 - 20.5	73	56	1.5 - 2.25	57-73	46-54	69-70	50-51
Haney	15.5 - 16.0	59	38 - 42	1.75 - 2.5	46-59	29-38	55-56	34-35
Lake Cowichan	16.1 - 16.1	49	29 - 32	1.1 - 1.6	34-49	21-29	45-46	25-26

TABLE 2

GAS PERMEABILITY EXPERIMENTAL DATA

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
INTERIOR SAPWOOD AIR DRIED										
~~23.28~~	~~25.5~~	~~7.8~~	~~170.2~~	~~59.8~~	~~170.2~~	~~10~~	~~0.688~~	~~2.87~~	~~0.4577~~	~~IS3 6~~
23.28	25.5	7.8	170.2	59.8	169.8	10	0.688	2.88	0.4587	IS3 6
6.92	25.5	8.2	152.4	60.0	134.2	1	0.217	0.39	-0.4143	IS3 19
~~6.92~~	~~25.5~~	~~8.2~~	~~152.4~~	~~60.0~~	~~134.2~~	~~1~~	~~0.217~~	~~0.39~~	~~-0.4143~~	~~IS3 19~~
6.44	25.3	7.9	154.9	60.0	93.2	1	0.208	0.56	-0.2504	IS3 21
6.44	25.3	7.9	154.9	60.0	94.6	1	0.208	0.55	-0.2569	IS3 21
~~23.40~~	~~25.5~~	~~8.4~~	~~233.7~~	~~60.0~~	~~44.2~~	~~1~~	~~0.467~~	~~0.74~~	~~-0.1281~~	~~IS3 24~~
23.40	25.5	8.4	233.7	60.0	44.6	1	0.467	0.74	-0.1320	IS3 24
24.50	24.5	8.6	188.0	60.0	28.8	1	0.619	1.33	0.1249	IS4 2
24.50	24.5	8.6	188.0	60.0	29.2	1	0.619	1.31	0.1189	IS4 2
23.90	25.6	8.3	200.7	60.0	33.6	1	0.561	1.16	0.0641	IS4 3
23.90	25.6	8.3	200.7	60.0	34.2	1	0.561	1.14	0.0564	IS4 3
16.84	25.5	8.7	190.5	60.0	67.2	1	0.398	0.58	-0.2366	IS4 5
16.84	25.5	8.7	190.5	58.0	67.8	1	0.398	0.59	-0.2257	IS4 5
8.98	25.5	8.6	154.9	60.0	142.2	1	0.264	0.34	-0.4673	IS4 8
8.98	25.5	8.6	154.9	59.8	143.4	1	0.264	0.34	-0.4695	IS4 8
7.26	25.4	8.3	154.9	60.0	123.8	1	0.222	0.40	-0.3934	IS4 14
7.26	25.4	8.3	154.9	60.0	124.2	1	0.222	0.40	-0.3948	IS4 14
INTERIOR HEARTWOOD AIR DRIED										
6.84	25.3	8.3	172.7	59.8	149.2	1	0.189	0.30	-0.5219	IH2 11
6.84	25.3	8.3	172.7	59.8	155.2	1	0.189	0.29	-0.5390	IH2 11
9.56	25.6	8.2	160.0	500.0	1000.0	1	0.285	0.01	-2.2269	IH2 13
9.56	25.6	8.2	160.0	500.0	1000.0	1	0.285	0.01	-2.2269	IH2 13
26.64	25.6	8.0	180.3	60.0	30.2	1	0.721	1.49	0.1727	IH2 18
26.64	25.6	8.0	180.3	60.0	29.0	1	0.721	1.55	0.1904	IH2 18
27.88	25.6	8.4	167.6	59.6	29.4	1	0.773	1.58	0.1978	IH2 20
27.88	25.6	8.4	167.6	59.6	30.0	1	0.773	1.55	0.1891	IH2 20

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
INTERIOR HEARTWOOD AIR DRIED										
19.50	25.5	8.5	147.3	59.6	10.4	1	0.611	4.99	0.6984	IH2 21
19.50	25.5	8.5	147.3	59.6	11.8	1	0.611	4.40	0.6436	IH2 21
8.30	25.5	8.5	170.2	59.6	27.6	1	0.225	1.63	0.2119	IH3 1
8.30	25.5	8.5	170.2	59.6	28.6	1	0.225	1.57	0.1964	IH3 1
7.14	25.5	8.2	170.2	59.8	52.0	1	0.201	0.89	-0.0490	IH3 3
7.14	25.5	8.2	170.2	59.8	56.8	1	0.201	0.82	-0.0874	IH3 3
6.58	25.4	8.1	162.6	500.0	1000.0	1	0.197	0.01	-2.2318	IH3 9
6.58	25.4	8.1	162.6	500.0	1000.0	1	0.197	0.01	-2.2318	IH3 9
26.40	25.5	8.3	165.1	59.8	24.2	1	0.756	1.95	0.2910	IH3 30
26.40	25.5	8.3	165.1	59.8	24.8	1	0.756	1.91	0.2804	IH3 30
COASTAL SAPWOOD AIR DRIED										
7.04	25.5	8.5	147.3	21.2	63.8	10	0.220	22.88	1.3595	CS3 10
7.04	25.5	8.5	147.3	21.1	68.6	10	0.220	21.38	1.3301	CS3 10
9.52	25.5	8.4	172.7	22.6	57.0	10	0.257	20.74	1.3168	CS3 13
9.52	25.5	8.4	172.7	22.4	56.5	10	0.257	21.11	1.3245	CS3 13
35.20	25.7	8.7	228.6	19.8	68.0	1	0.689	1.46	0.1640	CS3 15
35.20	25.7	8.7	228.6	19.8	67.6	1	0.689	1.47	0.1666	CS3 15
32.08	25.5	8.1	198.1	21.6	51.8	1	0.784	2.16	0.3342	CS4 1
32.08	25.5	8.1	198.1	21.5	55.0	1	0.784	2.04	0.3102	CS4 1
27.38	25.8	8.3	233.7	21.9	274.6	10	0.547	3.36	0.5266	CS4 3
27.38	25.8	8.3	233.7	21.7	301.2	10	0.547	3.09	0.4904	CS4 3
10.55	25.6	8.4	152.4	22.6	232.4	10	0.322	5.79	0.7625	CS4 4
10.55	25.6	8.4	152.4	22.1	260.8	10	0.322	5.27	0.7221	CS4 4
8.56	25.6	8.7	154.9	21.0	187.8	10	0.248	7.32	0.8645	CS4 8
8.56	25.6	8.7	154.9	21.2	189.6	10	0.248	7.18	0.8562	CS4 8

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
COASTAL HEARTWOOD AIR DRIED										
7.30	25.4	8.5	157.5	60.0	68.4	1	0.215	0.70	-0.1532	CH3 8
7.30	25.4	8.5	157.5	60.0	69.0	1	0.215	0.70	-0.1570	CH3 8
7.12	25.5	8.3	152.4	59.9	87.6	1	0.221	0.58	-0.2336	CH3 13
7.12	25.5	8.3	152.4	59.6	88.4	1	0.221	0.58	-0.2354	CH3 13
24.52	25.3	7.9	165.1	60.0	44.0	1	0.743	1.12	0.0480	CH3 15
24.52	25.3	7.9	165.1	60.0	44.6	1	0.743	1.10	0.0421	CH3 15
26.14	25.5	7.8	165.1	13.4	127.8	1	0.796	1.76	0.2449	CH3 19
26.14	25.5	7.8	165.1	13.4	141.0	1	0.796	1.59	0.2022	CH3 19
25.14	25.5	7.6	162.6	60.0	41.6	1	0.798	1.26	0.0993	CH3 22
25.14	25.5	7.6	162.6	60.0	42.8	1	0.798	1.22	0.0870	CH3 22
12.66	25.5	8.1	154.9	14.0	61.0	1	0.396	3.62	0.5583	CH3 23
12.66	25.5	8.1	154.9	14.0	65.8	1	0.396	3.35	0.5254	CH3 23
8.02	25.4	8.3	149.9	14.0	215.0	1	0.254	1.03	0.0133	CH4 2
8.02	25.4	8.3	149.9	14.0	219.2	1	0.254	1.01	0.0049	CH4 2
6.92	25.4	8.3	152.4	59.8	48.4	1	0.215	1.05	0.0231	CH4 5
6.92	25.4	8.3	152.4	60.0	54.8	1	0.215	0.93	-0.0323	CH4 5
6.68	25.5	8.1	152.4	60.0	133.2	1	0.212	0.39	-0.4057	CH4 11
8.62	25.4	7.9	149.9	13.8	157.8	1	0.287	1.50	0.1754	CH4 11
31.10	25.4	8.2	188.0	14.1	105.0	1	0.794	1.69	0.2284	CH4 13
31.10	25.4	8.2	188.0	14.1	110.0	1	0.794	1.62	0.2082	CH4 13
INTERIOR SAPWOOD OVEN DRIED										
20.77	25.5	7.8	172.7	61.1	40.2	1	0.605	1.17	0.0687	IS4 6
20.77	25.5	7.8	172.7	61.1	43.4	1	0.605	1.08	0.0354	IS4 6
6.18	25.3	7.5	154.9	60.2	278.4	1	0.210	0.20	-0.7045	IS4 19
6.18	25.3	7.5	154.9	60.1	275.2	1	0.210	0.20	-0.6988	IS4 19
6.30	25.4	7.6	154.9	60.2	395.8	1	0.211	0.14	-0.8614	IS4 21
6.30	25.4	7.6	154.9	60.3	411.8	1	0.211	0.13	-0.8793	IS4 21

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
INTERIOR SAPWOOD OVEN DRIED										
26.57	25.5	7.6	203.2	60.2	22.0	1	0.675	1.90	0.2776	IS4 24
26.57	25.5	7.6	203.2	60.2	22.4	1	0.675	1.86	0.2698	IS4 24
20.14	25.6	7.7	172.7	60.2	66.6	1	0.592	0.73	-0.1368	IS4 2
20.14	25.6	7.7	172.7	60.0	68.8	1	0.592	0.71	-0.1495	IS4 2
16.26	25.5	8.0	165.1	60.1	211.0	1	0.483	0.23	-0.6356	IS4 3
16.26	25.5	8.0	165.1	60.3	213.8	1	0.483	0.23	-0.6428	IS4 3
10.60	25.6	8.1	160.0	60.2	413.2	1	0.319	0.12	-0.9183	IS4 5
10.60	25.6	8.1	160.0	60.1	388.6	1	0.319	0.13	-0.8910	IS4 5
8.06	25.6	8.2	154.9	60.3	386.0	1	0.248	0.13	-0.8808	IS4 8
8.06	25.6	8.2	154.9	60.3	411.0	1	0.248	0.12	-0.9081	IS4 8
6.97	25.4	7.9	154.9	60.1	256.8	1	0.224	0.20	-0.6896	IS4 11
6.97	25.4	7.9	154.9	60.1	267.2	1	0.224	0.20	-0.7068	IS4 11
INTERIOR HEARTWOOD OVEN DRIED										
7.39	25.4	8.5	167.6	500.0	1000.0	1	0.204	0.01	-2.2661	IH2 4
7.39	25.4	8.5	167.6	500.0	1000.0	1	0.204	0.01	-2.2661	IH2 4
8.00	25.6	8.2	162.6	500.0	1000.0	1	0.234	0.01	-2.2337	IH2 9
8.00	25.6	8.2	162.6	500.0	1000.0	1	0.234	0.01	-2.2337	IH2 9
9.86	25.8	8.5	160.0	500.0	1000.0	1	0.281	0.01	-2.2391	IH2 13
9.86	25.8	8.5	160.0	500.0	1000.0	1	0.281	0.01	-2.2391	IH2 13
12.50	25.5	8.5	167.6	500.0	1000.0	1	0.344	0.01	-2.2644	IH2 15
12.50	25.5	8.5	167.6	500.0	1000.0	1	0.344	0.01	-2.2644	IH2 15
19.40	25.5	8.5	157.5	60.6	249.0	1	0.568	0.19	-0.7169	IH2 17
19.40	25.5	8.5	157.5	60.6	259.8	1	0.568	0.18	-0.7354	IH2 17
21.24	25.6	7.3	170.2	61.0	89.2	1	0.668	0.58	-0.2398	IH2 18
21.24	25.6	7.3	170.2	61.0	90.2	1	0.668	0.57	-0.2447	IH2 18
28.08	25.6	8.6	165.1	60.7	45.4	1	0.773	0.99	-0.0024	IH2 20
28.08	25.6	8.6	165.1	60.6	46.6	1	0.773	0.97	-0.0130	IH2 20
6.22	25.5	7.2	160.0	500.0	1000.0	1	0.212	0.01	-2.1721	IH3 9
6.22	25.5	7.2	160.0	500.0	1000.0	1	0.212	0.01	-2.1721	IH3 9

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
INTERIOR HEARTWOOD OVEN DRIED										
25.37	25.5	7.9	165.1	60.7	32.7	1	0.763	1.50	0.1753	IH3 30
25.37	25.5	7.9	165.1	60.6	32.7	1	0.763	1.50	0.1760	IH3 30
COASTAL SAPWOOD OVEN DRIED										
6.48	25.6	8.5	149.9	13.0	74.6	10	0.199	31.50	1.4983	CS3 10
6.48	25.6	8.5	149.9	13.0	75.2	10	0.199	31.25	1.4948	CS3 10
5.98	25.3	7.3	147.3	13.0	151.8	10	0.220	18.12	1.2582	CS3 11
5.98	25.3	7.3	147.3	13.0	160.8	10	0.220	17.11	1.2332	CS3 11
6.18	25.5	7.9	147.3	13.4	101.2	10	0.208	24.56	1.3902	CS3 13
6.18	25.5	7.9	147.3	13.4	108.0	10	0.208	23.01	1.3620	CS3 13
6.48	25.6	7.9	149.9	13.2	117.0	10	0.214	21.28	1.3280	CS3 14
6.48	25.6	7.9	149.9	13.1	126.6	10	0.214	19.82	1.2971	CS3 14
18.04	25.5	7.1	200.7	13.0	248.4	1	0.497	0.84	-0.0744	CS3 15
18.04	25.5	7.1	200.7	13.0	254.6	1	0.497	0.82	-0.0851	CS3 15
28.68	25.6	7.9	172.7	13.2	108.6	1	0.821	1.99	0.2987	CS4 2
28.68	25.6	7.9	172.7	13.3	117.2	1	0.821	1.83	0.2623	CS4 2
44.10	25.5	8.5	243.8	13.1	167.8	10	0.834	8.51	0.9298	CS4 3
44.10	25.5	8.5	243.8	13.0	172.4	10	0.834	8.34	0.9214	CS4 3
12.68	25.6	8.5	154.9	12.9	308.2	10	0.376	7.43	0.8711	CS4 5
12.68	25.6	8.5	154.9	12.9	323.8	10	0.376	7.07	0.8496	CS4 5
11.98	25.5	8.5	157.5	13.2	179.6	10	0.351	12.21	1.0869	CS4 6
11.98	25.5	8.5	157.5	13.3	182.4	10	0.351	11.94	1.0769	CS4 6
7.88	25.6	7.7	154.9	13.0	60.0	1	0.258	4.18	0.6213	CS4 8
7.88	25.6	7.7	154.9	13.0	61.0	1	0.258	4.11	0.6142	CS4 8
27.10	25.5	8.4	180.3	13.0	46.6	1	0.702	4.22	0.6257	CS5 2
27.10	25.5	8.4	180.3	13.0	49.4	1	0.702	3.98	0.6003	CS5 2

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
COASTAL HEARTWOOD OVEN DRIED										
6.84	25.6	8.4	152.4	60.0	83.0	1	0.209	0.61	-0.2144	CH3 9
6.84	25.6	8.4	152.4	60.0	80.6	1	0.209	0.63	-0.2017	CH3 9
26.40	25.5	7.7	172.7	19.7	92.0	1	0.778	1.61	0.2063	CH3 19
26.40	25.5	7.7	172.7	19.4	95.0	1	0.778	1.58	0.1990	CH3 19
24.64	25.6	7.8	162.6	19.8	99.4	1	0.759	1.56	0.1929	CH3 22
24.64	25.6	7.8	162.6	20.1	99.8	1	0.759	1.53	0.1846	CH3 22
23.28	25.4	7.8	175.3	19.8	77.8	1	0.670	1.83	0.2633	CH3 23
23.28	25.4	7.8	175.3	19.6	92.4	1	0.670	1.56	0.1930	CH3 23
13.72	25.5	8.0	162.6	19.5	57.4	1	0.414	2.66	0.4253	CH4 1
13.72	25.5	8.0	162.6	19.2	64.6	1	0.414	2.40	0.3807	CH4 1
6.26	25.4	8.0	157.5	60.0	53.4	1	0.196	0.96	-0.0193	CH4 11
6.26	25.4	8.0	157.5	59.8	55.0	1	0.196	0.93	-0.0307	CH4 11
7.72	25.5	8.3	172.7	59.8	44.6	1	0.211	1.01	0.0059	CH4 13
7.72	25.5	8.3	172.7	59.8	46.4	1	0.211	0.97	-0.0113	CH4 13
INTERIOR SAPWOOD SOLVENT DRIED										
6.48	25.4	8.1	149.9	12.7	123.2	10	0.210	20.33	1.3081	IS3 19
6.48	25.4	8.1	149.9	12.7	125.6	10	0.210	19.94	1.2997	IS3 19
8.38	25.5	7.7	198.1	12.7	161.4	10	0.215	12.40	1.0933	IS3 21
8.38	25.5	7.7	198.1	12.7	164.1	10	0.215	12.19	1.0861	IS3 21
23.08	25.5	8.2	180.3	12.7	621.6	10	0.612	3.32	0.5212	IS3 24
23.08	25.5	8.2	180.3	12.9	629.4	10	0.612	3.23	0.5090	IS3 24
22.08	25.6	8.2	175.3	12.7	134.0	10	0.600	15.91	1.2017	IS4 2
22.08	25.6	8.2	175.3	12.7	138.0	10	0.600	15.45	1.1889	IS4 2
16.66	25.5	8.1	160.0	12.7	94.2	10	0.504	25.00	1.3979	IS4 3
16.66	25.5	8.1	160.0	12.7	94.4	10	0.504	24.94	1.3969	IS4 3

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
INTERIOR SAPWOOD SOLVENT DRIED										
14.30	25.5	8.2	157.5	12.7	99.2	10	0.434	23.82	1.3770	IS4 4
14.30	25.5	8.2	157.5	12.7	99.8	10	0.434	23.68	1.3744	IS4 4
10.88	25.5	8.2	152.4	12.7	137.0	10	0.341	17.83	1.2511	IS4 5
10.88	25.5	8.2	152.4	12.7	135.6	10	0.341	18.01	1.2555	IS4 5
8.36	25.5	8.2	149.9	12.9	129.0	10	0.267	18.95	1.2777	IS4 8
8.36	25.5	8.2	149.9	12.9	131.2	10	0.267	18.64	1.2704	IS4 8
6.86	25.5	7.9	149.9	12.7	101.4	10	0.227	25.42	1.4052	IS4 14
6.86	25.5	7.9	149.9	12.9	100.2	10	0.227	25.33	1.4036	IS4 14
INTERIOR HEARTWOOD SOLVENT DRIED										
14.18	25.5	7.9	421.6	59.4	121.0	1	0.167	0.16	-0.7908	IH2 16
14.18	25.5	7.9	421.6	60.5	130.6	1	0.167	0.15	-0.8319	IH2 16
21.44	25.6	7.6	198.1	60.0	58.8	1	0.556	0.73	-0.1352	IH2 18
21.44	25.6	7.6	198.1	59.9	59.0	1	0.556	0.73	-0.1359	IH2 18
27.82	25.6	8.3	180.3	59.7	26.6	1	0.726	1.64	0.2141	IH2 20
27.82	25.6	8.3	180.3	59.5	28.2	1	0.726	1.55	0.1901	IH2 20
23.50	25.3	8.1	162.6	60.0	27.2	1	0.705	1.79	0.2527	IH2 22
23.50	25.3	8.1	162.6	59.9	29.4	1	0.705	1.66	0.2197	IH2 22
6.84	25.3	8.4	170.2	59.9	175.0	10	0.189	2.57	0.4093	IH3 3
6.84	25.3	8.4	170.2	59.9	193.6	10	0.189	2.32	0.3654	IH3 3
5.76	25.4	7.1	167.6	60.1	62.0	1	0.191	0.87	-0.0602	IH3 9
5.76	25.4	7.1	167.6	60.1	62.0	1	0.191	0.87	-0.0602	IH3 9

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
COASTAL SAPWOOD SOLVENT DRIED										
6.90	24.6	8.3	149.9	3.7	169.0	10	0.226	48.08	1.6819	CS3 10
6.90	24.6	8.3	149.9	3.7	176.2	10	0.226	46.11	1.6638	CS3 10
7.40	25.4	8.1	175.3	3.3	91.2	10	0.205	90.37	1.9560	CS3 14
7.40	25.4	8.1	175.3	3.3	92.6	10	0.205	89.00	1.9494	CS3 14
17.26	25.3	5.4	231.1	12.7	42.0	1	0.547	5.78	0.7616	CS3 15
17.26	25.3	5.4	231.1	12.7	42.2	1	0.547	5.75	0.7596	CS3 15
25.14	25.6	6.1	238.8	12.5	127.6	1	0.674	1.68	0.2240	CS4 1
25.14	25.6	6.1	238.8	12.5	129.8	1	0.674	1.65	0.2166	CS4 1
33.50	25.3	7.7	254.0	17.6	79.4	10	0.677	14.07	1.1483	CS4 3
33.50	25.3	7.7	254.0	17.5	81.0	10	0.677	13.87	1.1421	CS4 3
9.02	25.6	8.0	147.3	3.4	97.6	10	0.299	99.50	1.9978	CS4 5
9.02	25.6	8.0	147.3	3.3	99.6	10	0.299	100.45	2.0020	CS4 5
8.64	24.6	8.2	147.3	3.7	89.2	10	0.291	93.79	1.9721	CS4 6
8.64	24.6	8.2	147.3	3.5	91.2	10	0.291	96.97	1.9866	CS4 6
7.86	25.5	8.3	154.9	17.8	31.4	10	0.240	53.93	1.7318	CS4 8
7.86	25.5	8.3	154.9	3.1	153.4	10	0.240	63.38	1.8020	CS4 8
26.14	25.5	7.4	221.0	12.6	48.4	1	0.627	3.89	0.5896	CS5 2
26.14	25.5	7.4	221.0	12.5	49.8	1	0.627	3.81	0.5807	CS5 2
27.64	25.8	8.3	188.0	12.1	45.4	1	0.687	4.58	0.6605	CS5 3
27.64	25.8	8.3	188.0	12.1	47.6	1	0.687	4.36	0.6399	CS5 3
COASTAL HEARTWOOD SOLVENT DRIED										
7.05	25.6	8.3	146.0	12.8	130.4	1	0.227	1.92	0.2840	CH3 9
7.05	25.6	8.3	146.0	13.0	140.6	1	0.227	1.76	0.2446	CH3 9
6.56	25.2	8.1	151.1	12.7	129.0	1	0.213	1.91	0.2810	CH3 12
6.56	25.2	8.1	151.1	12.7	135.6	1	0.213	1.82	0.2593	CH3 12
16.50	25.5	7.8	151.1	12.7	240.8	1	0.549	1.08	0.0315	CH3 16
16.50	25.5	7.8	151.1	12.7	260.4	1	0.549	0.99	-0.0025	CH3 16
27.00	25.5	7.8	165.1	12.9	142.4	1	0.822	1.64	0.2144	CH3 19
27.00	25.5	7.8	165.1	13.3	149.6	1	0.822	1.51	0.1798	CH3 19
25.38	25.5	7.8	152.4	12.9	124.4	1	0.837	2.03	0.3079	CH3 22

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
COASTAL HEARTWOOD SOLVENT DRIED										
25.38	25.5	7.8	152.4	13.2	128.4	1	0.837	1.92	0.2842	CH3 22
11.98	25.5	7.9	142.2	13.1	23.6	1	0.418	11.16	1.0476	CH3 23
11.98	25.5	7.9	142.2	13.1	25.2	1	0.418	10.45	1.0191	CH3 23
15.30	25.4	8.0	157.5	10.7	127.4	1	0.478	2.25	0.3518	CH4 1
15.30	25.4	8.0	157.5	10.7	130.0	1	0.478	2.20	0.3430	CH4 1
8.38	25.5	8.2	149.9	12.6	205.2	1	0.267	1.22	0.0863	CH4 5
8.38	25.5	8.2	149.9	12.6	205.2	1	0.267	1.22	0.0863	CH4 5
6.54	25.5	8.3	152.4	10.6	235.6	1	0.203	1.23	0.0888	CH4 11
6.54	25.5	8.3	152.4	10.7	264.2	1	0.203	1.08	0.0350	CH4 11
23.58	25.6	8.1	170.2	13.0	147.2	1	0.668	1.48	0.1688	CH4 13
23.58	25.6	8.1	170.2	13.5	155.6	1	0.668	1.34	0.1283	CH4 13
INTERIOR SAPWOOD FREEZE DRIED										
24.38	25.5	8.1	177.8	19.7	44.6	1	0.664	3.06	0.4862	IS3 6
24.38	25.5	8.1	177.8	19.7	45.2	1	0.664	3.02	0.4804	IS3 6
6.58	25.4	8.2	152.4	19.5	193.8	1	0.207	0.82	-0.0875	IS3 19
6.58	25.4	8.2	152.4	19.4	213.0	1	0.207	0.75	-0.1263	IS3 19
25.50	25.5	7.8	284.5	19.2	105.2	1	0.451	0.86	-0.0631	IS3 24
25.50	25.5	7.8	284.5	19.0	112.6	1	0.451	0.82	-0.0881	IS3 24
21.70	25.4	8.2	165.1	20.0	72.0	1	0.631	1.98	0.2968	IS4 2
21.70	25.4	8.2	165.1	20.0	75.2	1	0.631	1.90	0.2779	IS4 2
8.56	25.4	8.1	154.9	19.6	55.0	1	0.269	2.85	0.4554	IS4 3
8.56	25.4	8.1	154.9	19.4	57.0	1	0.269	2.78	0.4444	IS4 3
10.86	25.5	7.9	157.5	19.3	196.4	10	0.342	8.22	0.9148	IS4 5
10.86	25.5	7.9	157.5	19.0	201.2	10	0.342	8.15	0.9111	IS4 5
7.54	25.5	7.6	149.9	19.8	35.0	1	0.260	4.91	0.6912	IS4 8
7.54	25.5	7.6	149.9	19.7	36.6	1	0.260	4.72	0.6739	IS4 8
7.28	25.4	8.2	152.4	19.6	170.6	10	0.229	9.24	0.9656	IS4 11
7.28	25.4	8.2	152.4	19.5	175.7	10	0.229	9.02	0.9551	IS4 11
7.60	25.3	8.6	152.4	20.0	31.0	1	0.229	4.73	0.6751	IS4 13
7.60	25.3	8.6	152.4	19.9	32.8	1	0.229	4.50	0.6528	IS4 13

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
INTERIOR HEARTWOOD FREEZE DRIED										
7.36	25.5	8.4	149.9	500.0	1000.0	1	0.229	0.01	-2.2106	IH2 4
7.36	25.5	8.4	149.9	500.0	1000.0	1	0.229	0.01	-2.2106	IH2 4
8.24	25.6	8.2	147.3	500.0	1000.0	1	0.266	0.01	-2.1910	IH2 9
8.24	25.6	8.2	147.3	500.0	1000.0	1	0.266	0.01	-2.1910	IH2 9
9.22	25.5	7.9	144.8	500.0	1000.0	1	0.316	0.01	-2.1689	IH2 13
9.22	25.5	7.9	144.8	500.0	1000.0	1	0.316	0.01	-2.1689	IH2 13
6.62	25.5	8.2	149.9	500.0	1000.0	1	0.211	0.01	-2.2001	IH3 9
6.62	25.5	8.2	149.9	500.0	1000.0	1	0.211	0.01	-2.2001	IH3 9
16.42	25.5	7.9	157.5	60.5	143.4	1	0.518	0.36	-0.4448	IH2 16
16.42	25.5	7.9	157.5	60.5	147.4	1	0.518	0.35	-0.4567	IH2 16
25.94	25.5	8.0	160.0	60.4	33.6	1	0.795	1.49	0.1737	IH2 18
25.94	25.5	8.0	160.0	60.4	33.8	1	0.795	1.48	0.1712	IH2 18
24.92	25.6	7.8	154.9	60.0	36.4	1	0.805	1.47	0.1686	IH2 20
24.92	25.6	7.8	154.9	60.0	36.2	1	0.805	1.48	0.1710	IH2 20
14.38	25.5	8.2	149.9	60.0	184.8	10	0.459	2.84	0.4540	IH2 22
14.38	25.5	8.2	149.9	60.0	187.2	10	0.459	2.81	0.4484	IH2 22
24.78	25.5	8.1	165.1	60.5	28.4	1	0.727	1.69	0.2271	IH3 30
24.78	25.5	8.1	165.1	60.5	28.7	1	0.727	1.67	0.2225	IH3 30
COASTAL SAPWOOD FREEZE DRIED										
6.90	25.4	8.2	151.1	4.5	156.8	10	0.219	44.15	1.6450	CS3 10
6.90	25.4	8.2	151.1	4.4	154.2	10	0.219	45.92	1.6620	CS3 10
6.36	25.7	8.1	147.3	4.2	117.0	10	0.207	66.62	1.8236	CS3 13
6.36	25.7	8.1	147.3	4.2	120.0	10	0.207	64.95	1.8126	CS3 13
9.72	25.3	8.5	162.6	4.3	109.2	10	0.278	59.27	1.7728	CS3 14
9.72	25.3	8.5	162.6	4.2	114.6	10	0.278	57.82	1.7621	CS3 14
20.32	25.6	8.5	175.3	4.4	63.4	1	0.533	9.36	0.9714	CS3 15
20.32	25.6	8.5	175.3	4.2	64.0	1	0.533	9.72	0.9876	CS3 15
32.86	25.4	8.3	203.2	4.4	233.0	1	0.767	2.23	0.3489	CS4 1
32.86	25.4	8.3	203.2	4.4	242.6	1	0.767	2.14	0.3313	CS4 1

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
COASTAL SAPWOOD FREEZE DRIED										
37.50	25.5	8.5	223.5	4.6	38.0	1	0.774	11.67	1.0671	CS4 3
37.50	25.5	8.5	223.5	4.4	38.8	1	0.774	11.95	1.0774	CS4 3
15.60	25.6	8.6	152.4	4.5	41.0	1	0.465	16.09	1.2066	CS4 4
15.60	25.6	8.6	152.4	4.4	43.0	1	0.465	15.69	1.1957	CS4 4
8.90	25.7	8.7	149.9	4.2	163.2	10	0.266	43.71	1.6406	CS4 6
8.90	25.7	8.7	149.9	4.2	162.2	10	0.266	43.98	1.6433	CS4 6
8.39	25.7	8.5	154.9	4.4	164.4	10	0.248	41.01	1.6128	CS4 8
8.39	25.7	8.5	154.9	4.5	166.4	10	0.248	39.61	1.5978	CS4 8
28.20	25.5	8.6	170.2	4.4	136.2	1	0.756	4.42	0.6453	CS5 3
28.20	25.5	8.6	170.2	4.4	143.8	1	0.756	4.19	0.6218	CS5 3
COASTAL HEARTWOOD FREEZE DRIED										
10.70	25.6	8.0	149.9	20.0	66.6	1	0.349	2.44	0.3868	CH3 9
10.70	25.6	8.0	149.9	19.8	73.8	1	0.349	2.22	0.3466	CH3 9
7.12	25.4	8.2	147.3	60.0	60.6	1	0.232	0.88	-0.0560	CH3 13
7.12	25.4	8.2	147.3	60.0	62.8	1	0.232	0.85	-0.0715	CH3 13
23.88	25.5	7.7	167.6	19.8	149.2	1	0.725	1.02	0.0071	CH3 23
23.88	25.5	7.7	167.6	19.8	150.0	1	0.725	1.01	0.0048	CH3 23
22.88	25.5	7.8	154.9	60.0	35.4	1	0.742	1.51	0.1790	CH4 5
22.88	25.5	7.8	154.9	59.9	35.6	1	0.742	1.50	0.1772	CH4 5
6.98	25.5	8.1	162.6	20.2	56.0	1	0.208	2.60	0.4153	CH4 13
6.98	25.5	8.1	162.6	20.0	60.6	1	0.208	2.43	0.3854	CH4 13

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
INTERIOR SAPWOOD BOILED UNDER VACUUM										
18.04	25.5	6.8	167.6	19.9	49.2	1	0.621	3.47	0.5407	IS3 6
18.04	25.5	6.8	167.6	19.9	50.4	1	0.621	3.39	0.5302	IS3 6
6.26	25.4	7.5	157.5	19.0	240.0	1	0.209	0.72	-0.1446	IS3 19
6.26	25.4	7.5	157.5	19.2	288.6	1	0.209	0.59	-0.2292	IS3 19
6.96	25.3	8.6	157.5	60.8	115.2	1	0.203	0.41	-0.3921	IS3 21
13.82	25.5	8.5	180.3	19.3	186.1	1	0.354	0.70	-0.1524	IS3 24
13.82	25.5	8.5	180.3	19.0	191.5	1	0.354	0.69	-0.1580	IS3 24
25.19	25.6	8.4	167.6	18.8	39.0	1	0.699	3.77	0.5762	IS4 2
25.19	25.6	8.4	167.6	19.7	39.2	1	0.699	3.58	0.5537	IS4 2
23.14	25.6	8.5	172.7	19.3	27.2	1	0.616	5.05	0.7032	IS4 3
23.14	25.6	8.5	172.7	18.9	28.0	1	0.616	5.01	0.6997	IS4 3
16.49	25.5	8.4	154.9	19.8	80.8	1	0.497	1.86	0.2699	IS4 4
16.49	25.5	8.4	154.9	19.7	84.2	1	0.497	1.80	0.2542	IS4 4
13.68	25.6	8.5	162.6	62.5	75.8	1	0.387	0.59	-0.2259	IS4 5
13.68	25.6	8.5	162.6	62.3	83.8	1	0.387	0.54	-0.2681	IS4 5
9.20	25.4	8.5	157.5	20.2	983.0	1	0.271	0.15	-0.8379	IS4 8
9.20	25.4	8.5	157.5	61.3	318.2	1	0.271	0.15	-0.8301	IS4 8
7.98	25.5	8.4	154.9	59.5	273.4	1	0.240	0.18	-0.7374	IS4 11
7.98	25.5	8.4	154.9	59.5	275.8	1	0.240	0.18	-0.7412	IS4 11
7.47	25.5	8.6	157.5	61.5	199.5	1	0.216	0.23	-0.6322	IS4 14
7.47	25.5	8.6	157.5	61.3	225.0	1	0.216	0.21	-0.6830	IS4 14
INTERIOR HEARTWOOD BOILED UNDER VACUUM										
7.66	25.5	8.2	167.6	500.0	1000.0	1	0.219	0.01	-2.2488	IH2 4
7.66	25.5	8.2	167.6	500.0	1000.0	1	0.219	0.01	-2.2488	IH2 4
8.68	25.6	7.9	162.6	500.0	1000.0	1	0.264	0.01	-2.2175	IH2 9
8.68	25.6	7.9	162.6	500.0	1000.0	1	0.264	0.01	-2.2175	IH2 9
26.50	25.4	8.1	182.9	60.4	60.0	1	0.704	0.72	-0.1432	IH2 16
26.50	25.4	8.1	182.9	60.4	59.2	1	0.704	0.73	-0.1373	IH2 16

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
INTERIOR HEARTWOOD BOILED UNDER VACUUM										
27.36	25.5	8.0	182.9	60.5	38.6	1	0.733	1.13	0.0548	IH2 18
27.36	25.5	8.0	182.9	60.5	38.6	1	0.733	1.13	0.0548	IH2 18
16.50	25.5	8.5	154.9	60.6	24.6	1	0.491	1.97	0.2954	IH3 31
16.50	25.5	8.5	154.9	60.6	25.0	1	0.491	1.94	0.2884	IH3 31
COASTAL SAPWOOD BOILED UNDER VACUUM										
7.38	25.6	8.5	147.3	3.9	116.6	10	0.230	68.33	1.8346	CS3 10
7.38	25.6	8.5	147.3	3.6	122.8	10	0.230	70.29	1.8469	CS3 10
7.00	25.5	8.5	154.9	3.8	86.6	10	0.208	89.43	1.9515	CS3 13
7.00	25.5	8.5	154.9	3.4	95.0	10	0.208	91.12	1.9596	CS3 13
7.76	25.2	8.5	162.6	3.8	91.4	10	0.223	79.81	1.9021	CS3 14
7.76	25.2	8.5	162.6	3.6	94.7	10	0.223	81.31	1.9102	CS3 14
17.66	25.6	8.5	200.7	4.2	149.3	10	0.404	36.38	1.5609	CS3 15
17.66	25.6	8.5	200.7	3.7	164.8	10	0.404	37.41	1.5730	CS3 15
32.86	25.6	8.5	193.0	19.9	376.4	10	0.782	3.17	0.5005	CS4 1
32.86	25.6	8.5	193.0	19.8	45.0	1	0.782	2.66	0.4251	CS4 1
45.38	25.5	8.5	274.3	4.4	27.0	1	0.763	13.99	1.1459	CS4 3
45.38	25.5	8.5	274.3	4.3	28.2	1	0.763	13.71	1.1370	CS4 3
16.74	25.6	8.5	142.2	4.6	36.4	1	0.541	19.22	1.2838	CS4 4
16.74	25.6	8.5	142.2	4.6	36.8	1	0.541	19.01	1.2790	CS4 4
9.64	25.2	8.5	147.3	4.3	125.0	10	0.305	56.91	1.7552	CS4 6
9.64	25.2	8.5	147.3	4.2	128.2	10	0.305	56.81	1.7544	CS4 6
8.58	25.6	8.5	154.9	3.8	171.0	10	0.254	45.47	1.6577	CS4 8
8.58	25.6	8.5	154.9	3.6	181.4	10	0.254	45.24	1.6556	CS4 8

TABLE 2 (CONTINUED)

WEIGHT MG	LENGTH MM	WIDTH MM	THICK MICRON	PRESSURE MM HG	TIME SEC	VOLUME ML	SP GR	PERM DARCIES	LOG PERM	IDENT
COASTAL HEARTWOOD BOILED UNDER VACUUM										
14.30	24.9	8.3	170.2	20.6	77.6	1	0.407	1.68	0.2243	CH3 13
14.30	24.9	8.3	170.2	20.6	84.4	1	0.407	1.54	0.1878	CH3 13
27.28	25.4	8.1	167.6	20.4	70.6	1	0.791	1.97	0.2954	CH3 15
27.28	25.4	8.1	167.6	20.4	72.4	1	0.791	1.93	0.2844	CH3 15
26.40	25.3	7.9	175.3	20.2	57.0	1	0.754	2.41	0.3824	CH3 19
26.40	25.3	7.9	175.3	20.2	58.8	1	0.754	2.34	0.3689	CH3 19
19.26	25.5	8.1	160.0	20.4	45.6	1	0.583	3.21	0.5071	CH3 22
19.26	25.5	8.1	160.0	20.4	47.4	1	0.583	3.09	0.4903	CH3 22
10.38	25.5	8.4	157.5	20.4	60.8	1	0.308	2.36	0.3733	CH3 23
10.38	25.5	8.4	157.5	20.4	64.0	1	0.308	2.24	0.3511	CH3 23
8.46	25.5	8.4	160.0	59.8	145.4	1	0.247	0.33	-0.4793	CH4 1
8.46	25.5	8.4	160.0	60.0	168.8	1	0.247	0.28	-0.5456	CH4 1
30.54	25.5	7.8	175.3	20.0	53.2	1	0.876	2.66	0.4257	CH4 13
30.54	25.5	7.8	175.3	19.7	55.0	1	0.876	2.62	0.4178	CH4 13
10.54	25.4	8.7	172.7	60.0	40.2	1	0.276	1.07	0.0274	CH4 11
10.54	25.4	8.7	172.7	60.0	43.4	1	0.276	0.99	-0.0058	CH4 11

TABLE 3

Regressions of Douglas fir gas-permeability vs. specific gravity

Regressions have the form log P = a + bG

where P = permeability (darcies)

G = specific gravity

a, b = constants tabulated below

Drying method	a	b	n	R	SEE
Interior-type sapwood					
air-dried	-0.751	1.509	20	0.93 **	0.109
oven-dried	-1.339	1.211	20	0.91 **	0.188
solvent-dried	-1.383	-0.685	20	0.45 *	0.234
freeze-dried	-0.464	-0.473	18	0.22 n.s.	0.375
boiled-under-vacuum	-1.150	1.267	22	0.91 **	0.231
Interior-type heartwood					
air-dried	-1.407	2.308	18	0.56 *	0.899
oven-dried	-3.339	1.446	18	0.98 **	0.212
solvent-dried	0.022	0.045	11	0.03 n.s.	0.307
freeze-dried	-3.050	4.447	18	0.88 **	0.599
boiled-under-vacuum	-2.291	3.410	12	0.72 **	0.795
Coast-type sapwood					
air-dried	1.405	-1.528	18	0.84 **	0.217
oven-dried	1.389	-1.189	22	0.60 **	0.391
solvent-dried	2.572	-2.907	20	0.90 **	0.289
freeze-dried	2.155	-1.955	20	0.92 **	0.196
boiled-under-vacuum	2.307	-1.941	18	0.93 **	0.173
Coast-type heartwood					
air-dried	-0.150	0.441	22	0.46 *	0.229
oven-dried	-0.369	0.829	20	0.59 **	0.283
solvent-dried	0.268	0.001	20	0.00 n.s.	0.292
freeze-dried	0.121	-0.054	16	0.06 n.s.	0.196
boiled-under-vacuum	-0.226	0.815	18	0.66 **	0.236

TABLE 4

RATE OF CREOSOTE ABSORPTION IN GROSS SPECIMENS

	TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
INTERIOR SAPWOOD (PRINCE GEORGE) AIR DRIED				
	0.3	-0.5229	1.0	0.0000
	7.2	0.8573	5.0	0.6990
	24.0	1.3802	9.0	0.9542
	44.0	1.6435	13.0	1.1139
	60.0	1.7782	15.0	1.1761
	76.0	1.8808	17.0	1.2304
	126.0	2.1004	21.0	1.3222
	180.0	2.2553	23.0	1.3617
INTERIOR HEARTWOOD (PRINCE GEORGE) AIR DRIED				
	17.0	1.2304	2.0	0.3010
	40.0	1.6021	3.0	0.4771
	60.0	1.7782	3.5	0.5441
COASTAL SAPWOOD (HANEY) AIR DRIED				
	0.8	-0.1249	5.0	0.6990
	2.5	0.3979	10.0	1.0000
	6.0	0.7782	15.0	1.1761
	11.0	1.0414	20.0	1.3010
	21.0	1.3222	25.0	1.3979
	38.0	1.5798	30.0	1.4771
	61.0	1.7853	35.0	1.5441
	93.0	1.9685	40.0	1.6021
	120.0	2.0792	43.0	1.6335
	136.0	2.1335	45.0	1.6532

TABLE 4 (CONTINUED)

TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
COASTAL HEARTWOOD (HANEY) AIR DRIED			
0.5	-0.3010	1.0	0.0000
7.5	0.8751	3.5	0.5441
27.0	1.4314	6.0	0.7782
60.0	1.7782	8.5	0.9294
120.0	2.0792	11.0	1.0414
150.0	2.1761	12.0	1.0792
180.0	2.2553	12.5	1.0969
COASTAL SAPWOOD (COWICHAN) AIR DRIED			
4.0	0.6021	4.0	0.6021
14.0	1.1461	9.0	0.9542
25.0	1.3979	14.0	1.1461
37.0	1.5682	19.0	1.2788
55.0	1.7404	24.0	1.3802
75.0	1.8751	29.0	1.4624
99.0	1.9956	34.0	1.5315
127.0	2.1038	39.0	1.5911
161.0	2.2068	44.0	1.6435
COASTAL HEARTWOOD (COWICHAN) AIR DRIED			
2.0	0.3010	1.0	0.0000
16.0	1.2041	2.0	0.3010
60.0	1.7782	3.5	0.5441
90.0	1.9542	4.0	0.6021
180.0	2.2553	5.0	0.6990
INTERIOR SAPWOOD (PRINCE GEORGE) OVEN DRIED			
0.3	-0.5229	5.0	0.6990

TABLE 4 (CONTINUED)

TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
INTERIOR SAPWOOD (PRINCE GEORGE) OVEN DRIED			
1.0	0.0000	10.0	1.0000
2.2	0.3424	15.0	1.1761
3.7	0.5682	20.0	1.3010
6.0	0.7782	25.0	1.3979
9.1	0.9590	35.0	1.5441
12.9	1.1106	35.0	1.5441
17.7	1.2480	40.0	1.6021
26.3	1.4200	45.0	1.6532
INTERIOR HEARTWOOD (PRINCE GEORGE) OVEN DRIED			
1.7	0.2304	2.0	0.3010
30.0	1.4771	3.5	0.5441
60.0	1.7782	4.0	0.6021
90.0	1.9542	4.5	0.6532
120.0	2.0792	5.0	0.6990
150.0	2.1761	5.5	0.7404
180.0	2.2553	6.0	0.7782
COASTAL SAPWOOD (HANEY) OVEN DRIED			
0.2	-0.6990	5.0	0.6990
0.7	-0.1549	10.0	1.0000
1.2	0.0792	15.0	1.1761
1.8	0.2553	20.0	1.3010
3.0	0.4771	25.0	1.3979
4.5	0.6532	30.0	1.4771
7.5	0.8751	35.0	1.5441
12.0	1.0792	40.0	1.6021
22.8	1.3579	45.0	1.6532

TABLE 4 (CONTINUED)

TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
COASTAL HEARTWOOD (HANEY) OVEN DRIED			
0.2	-0.6990	5.0	0.6990
11.2	1.0492	10.0	1.0000
15.0	1.1761	11.0	1.0414
30.0	1.4771	15.0	1.1761
45.0	1.6532	18.0	1.2553
60.0	1.7782	20.0	1.3010
90.0	1.9542	23.0	1.3617
105.0	2.0212	24.0	1.3802
120.0	2.0792	26.0	1.4150
135.0	2.1303	27.0	1.4314
180.0	2.2553	30.0	1.4771
COASTAL SAPWOOD (COWICHAN) OVEN DRIED			
0.5	-0.3010	2.0	0.3010
2.5	0.3979	8.0	0.9031
6.0	0.7782	13.0	1.1139
10.4	1.0170	18.0	1.2553
15.4	1.1875	23.0	1.3617
23.5	1.3711	28.0	1.4472
34.7	1.5403	33.0	1.5185
47.8	1.6794	38.0	1.5798
64.5	1.8096	43.0	1.6335
90.0	1.9542	48.0	1.6812
COASTAL HEARTWOOD (COWICHAN) OVEN DRIED			
3.0	0.4771	3.0	0.4771
15.0	1.1761	5.5	0.7404
30.0	1.4771	8.0	0.9031
60.0	1.7782	12.5	1.0969

TABLE 4 (CONTINUED)

	TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
COASTAL HEARTWOOD (COWICHAN) OVEN DRIED				
	90.0	1.9542	15.0	1.1761
	120.0	2.0792	17.0	1.2304
	150.0	2.1761	18.5	1.2672
	180.0	2.2553	19.5	1.2900
INTERIOR SAPWOOD (PRINCE GEORGE) SOLVENT DRIED				
	0.2	-0.6990	5.0	0.6990
	0.5	-0.3010	10.0	1.0000
	0.9	-0.0458	15.0	1.1761
	1.5	0.1761	20.0	1.3010
	2.4	0.3802	25.0	1.3979
	3.8	0.5798	30.0	1.4771
	5.5	0.7404	35.0	1.5441
	7.5	0.8751	40.0	1.6021
	10.5	1.0212	45.0	1.6532
INTERIOR HEARTWOOD (PRINCE GEORGE) SOLVENT DRIED				
	1.2	0.0792	0.5	-0.3010
	9.0	0.9542	1.5	0.1761
	29.0	1.4624	2.5	0.3979
	41.5	1.6180	3.5	0.5441
	60.0	1.7782	4.5	0.6532
	120.0	2.0792	5.0	0.6990
	180.0	2.2553	5.5	0.7404
COASTAL SAPWOOD (HANEY) SOLVENT DRIED				
	0.5	-0.3010	5.0	0.6990
	1.0	0.0000	10.0	1.0000

TABLE 4 (CONTINUED)

TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
COASTAL SAPWOOD (HANEY) SOLVENT DRIED			
1.5	0.1761	15.0	1.1761
2.5	0.3979	20.0	1.3010
4.0	0.6021	25.0	1.3979
7.0	0.8451	30.0	1.4771
12.0	1.0792	35.0	1.5441
19.0	1.2788	40.0	1.6021
29.0	1.4624	44.0	1.6435
COASTAL HEARTWOOD (HANEY) SOLVENT DRIED			
3.0	0.4771	2.5	0.3979
6.0	0.7782	4.0	0.6021
30.0	1.4771	12.5	1.0969
60.0	1.7782	18.0	1.2553
90.0	1.9542	22.0	1.3424
120.0	2.0792	25.0	1.3979
150.0	2.1761	28.0	1.4472
180.0	2.2553	30.0	1.4771
COASTAL SAPWOOD (COWICHAN) SOLVENT DRIED			
0.2	-0.6990	5.0	0.6990
0.8	-0.0969	10.0	1.0000
1.3	0.1139	15.0	1.1761
2.3	0.3617	20.0	1.3010
3.5	0.5441	25.0	1.3979
5.2	0.7160	30.0	1.4771
7.2	0.8573	35.0	1.5441
9.5	0.9777	40.0	1.6021
12.8	1.1072	45.0	1.6532

TABLE 4 (CONTINUED)

	TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
COASTAL HEARTWOOD (COWICHAN) SOLVENT DRIED				
	1.6	0.2041	1.0	0.0000
	15.0	1.1761	5.0	0.6990
	19.2	1.2833	6.0	0.7782
	68.0	1.8325	11.0	1.0414
	118.0	2.0719	16.0	1.2041
INTERIOR SAPWOOD (PRINCE GEORGE) FREEZE DRIED				
	0.4	-0.3979	11.0	1.0414
	1.0	0.0000	15.0	1.1761
	2.5	0.3979	18.0	1.2553
	4.5	0.6532	23.0	1.3617
	7.0	0.8451	27.0	1.4314
	10.5	1.0212	31.0	1.4914
	14.5	1.1614	35.0	1.5441
INTERIOR HEARTWOOD (PRINCE GEORGE) FREEZE DRIED				
	60.0	1.7782	1.0	0.0000
	120.0	2.0792	1.0	0.0000
	180.0	2.2553	2.0	0.3010
COASTAL SAPWOOD (HANEY) FREEZE DRIED				
	0.1	-1.0000	3.0	0.4771
	0.2	-0.6990	10.0	1.0000
	0.5	-0.3010	15.0	1.1761
	0.9	-0.0458	20.0	1.3010
	1.5	0.1761	25.0	1.3979
	2.2	0.3424	30.0	1.4771
	3.2	0.5051	35.0	1.5441

TABLE 4 (CONTINUED)

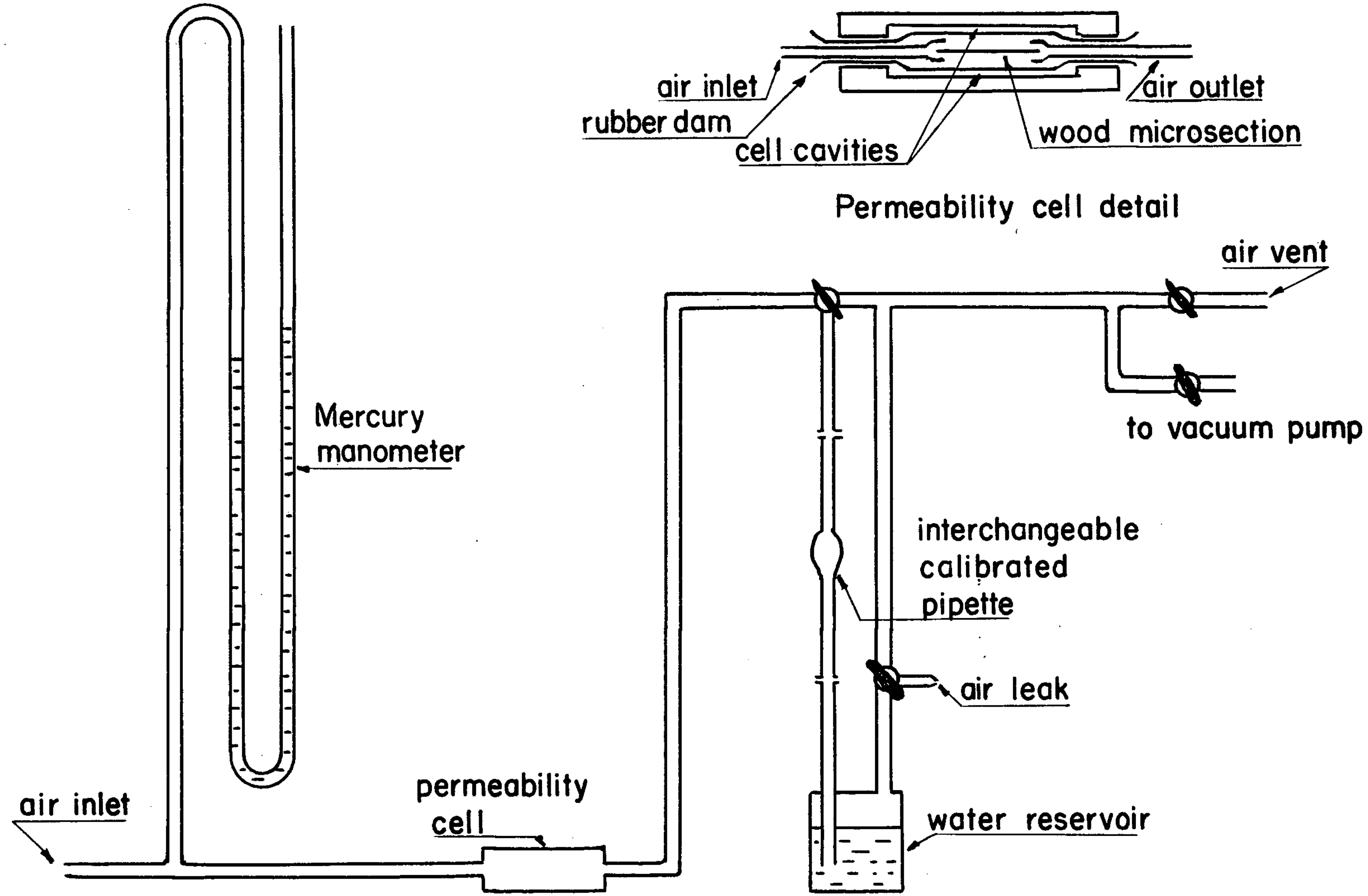
TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
COASTAL SAPWOOD (HANEY) FREEZE DRIED			
4.5	0.6532	40.0	1.6021
6.2	0.7924	45.0	1.6532
COASTAL HEARTWOOD (HANEY) FREEZE DRIED			
3.5	0.5441	5.0	0.6990
13.0	1.1139	10.0	1.0000
30.0	1.4771	15.0	1.1761
54.0	1.7324	20.0	1.3010
82.0	1.9138	25.0	1.3979
135.0	2.1303	30.0	1.4771
170.0	2.2304	32.5	1.5119
COASTAL SAPWOOD (COWICHAN) FREEZE DRIED			
0.2	-0.6990	5.0	0.6990
0.8	-0.0969	10.0	1.0000
1.7	0.2304	15.0	1.1761
2.5	0.3979	20.0	1.3010
3.5	0.5441	25.0	1.3979
5.5	0.7404	30.0	1.4771
7.5	0.8751	35.0	1.5441
10.0	1.0000	40.0	1.6021
13.4	1.1271	45.0	1.6532
COASTAL HEARTWOOD (COWICHAN) FREEZE DRIED			
19.0	1.2788	5.0	0.6990
60.0	1.7782	8.0	0.9031
75.0	1.8751	9.0	0.9542
102.0	2.0086	10.0	1.0000
180.0	2.2553	11.5	1.0607

TABLE 4 (CONTINUED)

TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
INTERIOR SAPWOOD (PRINCE GEORGE) BOILED UNDER VACUUM			
4.2	0.6232	5.0	0.6990
10.0	1.0000	9.0	0.9542
21.3	1.3284	14.0	1.1461
40.0	1.6021	18.0	1.2553
69.0	1.8388	23.0	1.3617
104.0	2.0170	27.0	1.4314
155.0	2.1903	32.0	1.5051
180.0	2.2553	33.0	1.5185
INTERIOR HEARTWOOD (PRINCE GEORGE) BOILED UNDER VACUUM			
1.5	0.1761	1.0	0.0000
60.0	1.7782	2.0	0.3010
120.0	2.0792	2.0	0.3010
180.0	2.2553	2.0	0.3010
COASTAL SAPWOOD (HANEY) BOILED UNDER VACUUM			
0.4	-0.3979	5.0	0.6990
1.6	0.2041	10.0	1.0000
3.3	0.5185	15.0	1.1761
5.4	0.7324	20.0	1.3010
9.1	0.9590	25.0	1.3979
15.2	1.1818	30.0	1.4771
24.9	1.3962	35.0	1.5441
44.8	1.6513	40.0	1.6021
75.0	1.8751	43.0	1.6335
COASTAL HEARTWOOD (HANEY) BOILED UNDER VACUUM			
8.0	0.9031	4.0	0.6021

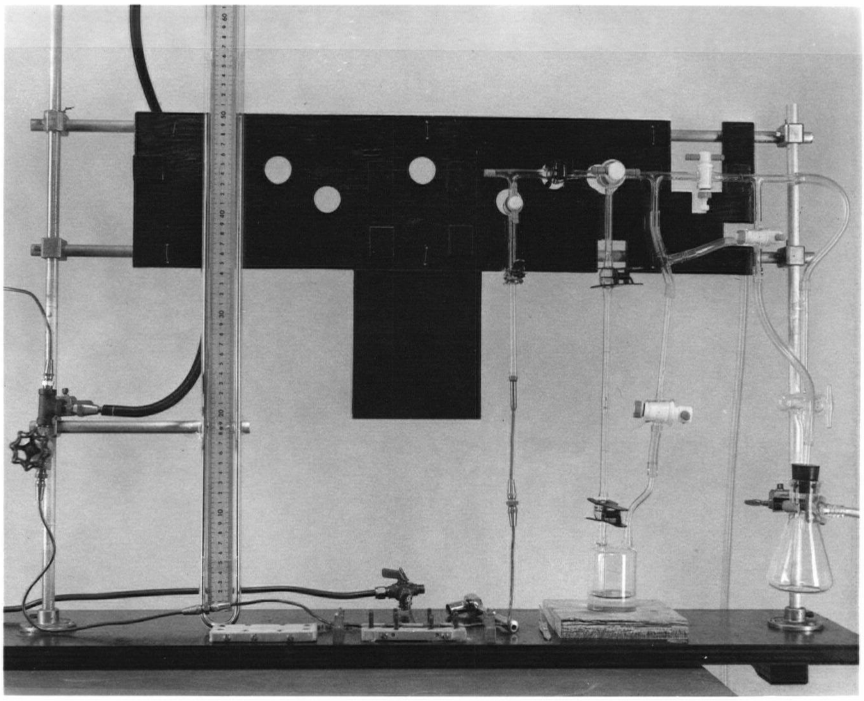
TABLE 4 (CONTINUED)

TIME MINUTES	LOG TIME	RETENTION GRAMS	LOG RET
COASTAL HEARTWOOD (HANEY) BOILED UNDER VACUUM			
17.0	1.2304	5.0	0.6990
27.0	1.4314	6.0	0.7782
60.0	1.7782	8.0	0.9031
120.0	2.0792	11.0	1.0414
180.0	2.2553	13.5	1.1303
COASTAL SAPWOOD (COWICHAN) BOILED UNDER VACUUM			
1.0	0.0000	5.0	0.6990
2.5	0.3979	7.5	0.8751
4.0	0.6021	10.0	1.0000
8.5	0.9294	15.0	1.1761
14.5	1.1614	20.0	1.3010
24.0	1.3802	25.0	1.3979
40.0	1.6021	30.0	1.4771
66.0	1.8195	35.0	1.5441
116.0	2.0645	40.0	1.6021
180.0	2.2553	42.5	1.6284
COASTAL HEARTWOOD (COWICHAN) BOILED UNDER VACUUM			
0.6	-0.1871	2.0	0.3010
15.0	1.1761	5.0	0.6990
30.0	1.4771	7.0	0.8451
45.0	1.6532	8.5	0.9294
60.0	1.7782	9.5	0.9777
75.0	1.8751	10.5	1.0212
90.0	1.9542	11.5	1.0607
105.0	2.0212	12.0	1.0792
120.0	2.0792	12.7	1.1038



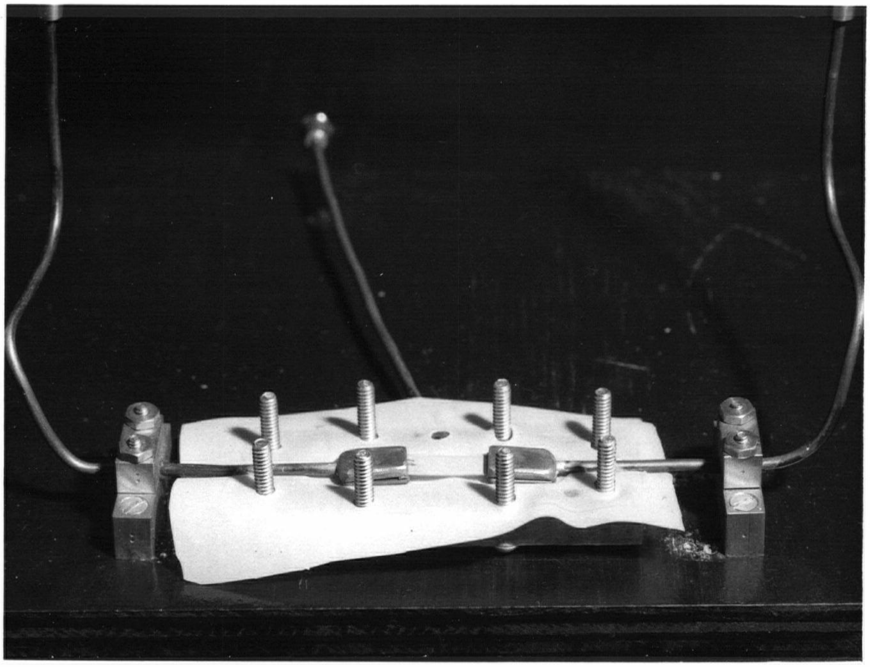
Gas-permeability apparatus

FIGURE 1



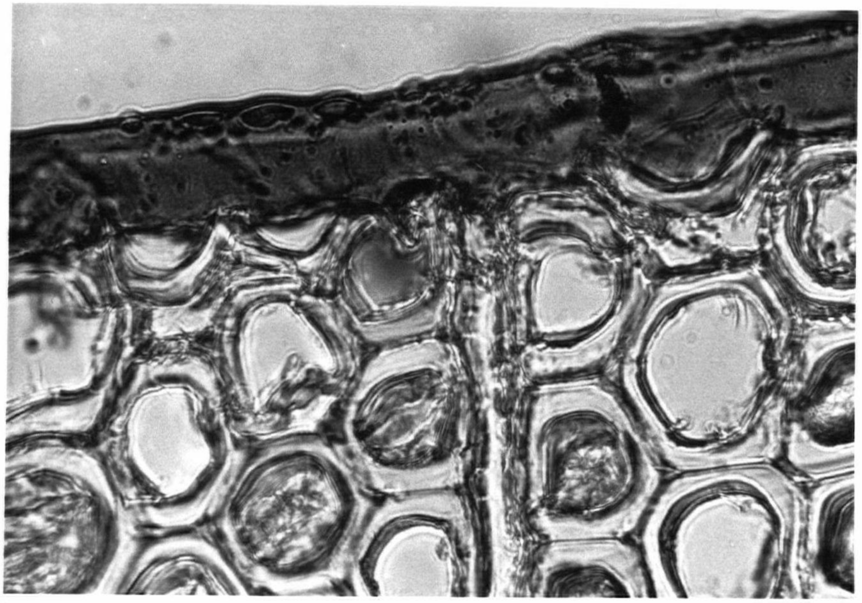
Gas permeability apparatus

FIGURE 2



Permeability cell

FIGURE 3

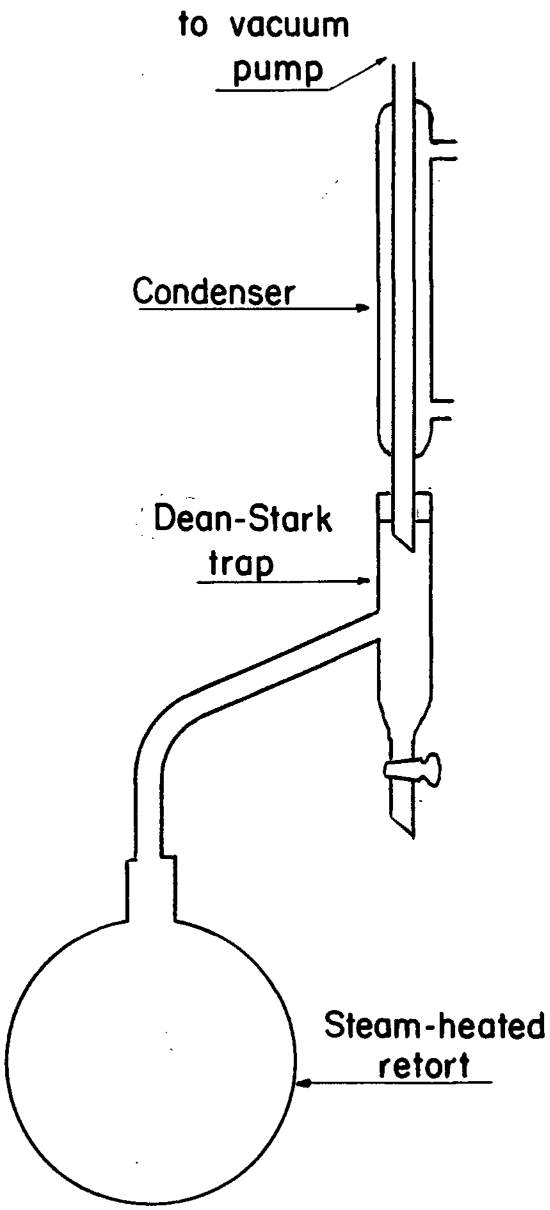


a. Adhesive on cellulose tape has not completely penetrated surface cavities

b. Adhesive on cellulose tape has completely penetrated surface cavities

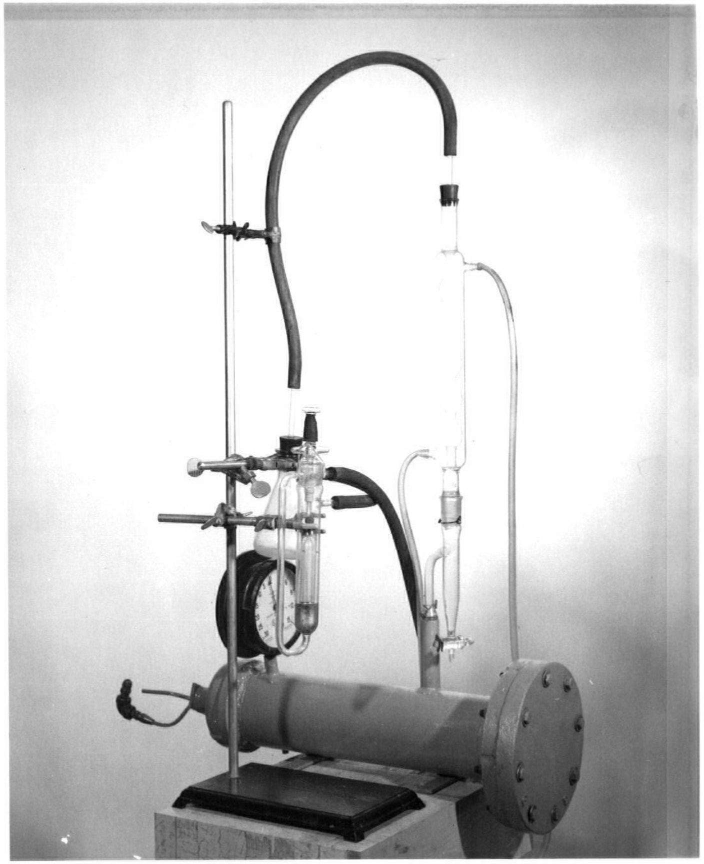
Microsection cross section

FIGURE 4



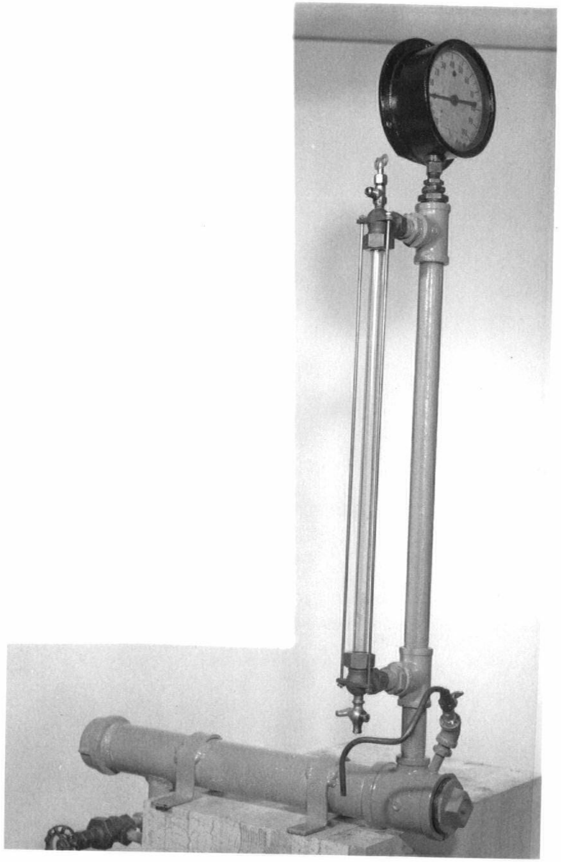
Boiling-under-vacuum apparatus

FIGURE 5



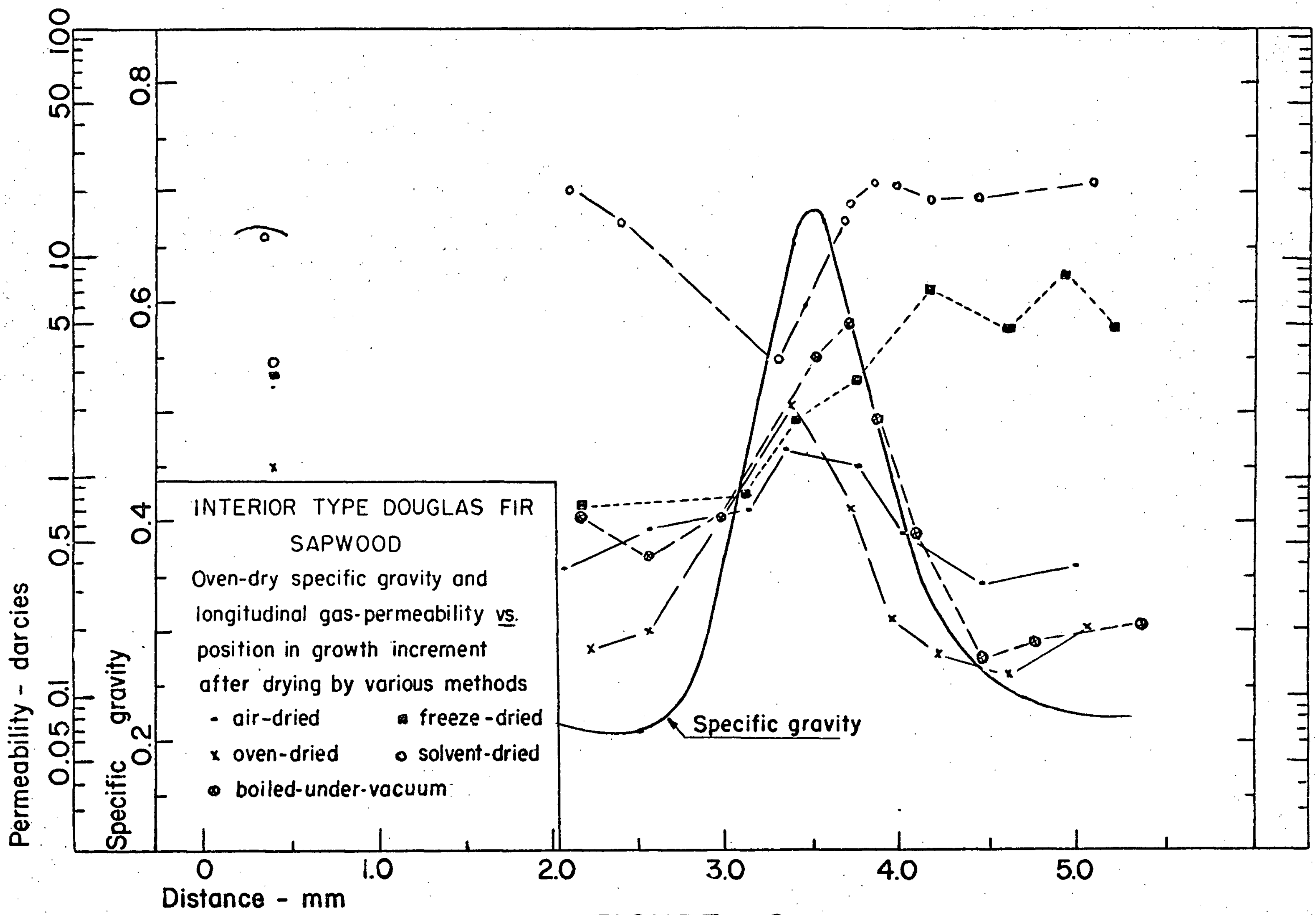
Boiling-under-vacuum apparatus

FIGURE 6



Pressure retort

FIGURE 7



INTERIOR TYPE DOUGLAS FIR
SAPWOOD
Oven-dry specific gravity and longitudinal gas-permeability vs. position in growth increment after drying by various methods
air-dried
freeze-dried
oven-dried
solvent-dried
boiled-under-vacuum
Specific gravity
Permeability - darcies
Specific gravity
Distance - mm
100
50
10
5
1
0.5
0.1
0.05
0.8
0.6
0.4
0.2
0
1.0
2.0
3.0
4.0
5.0

FIGURE 8

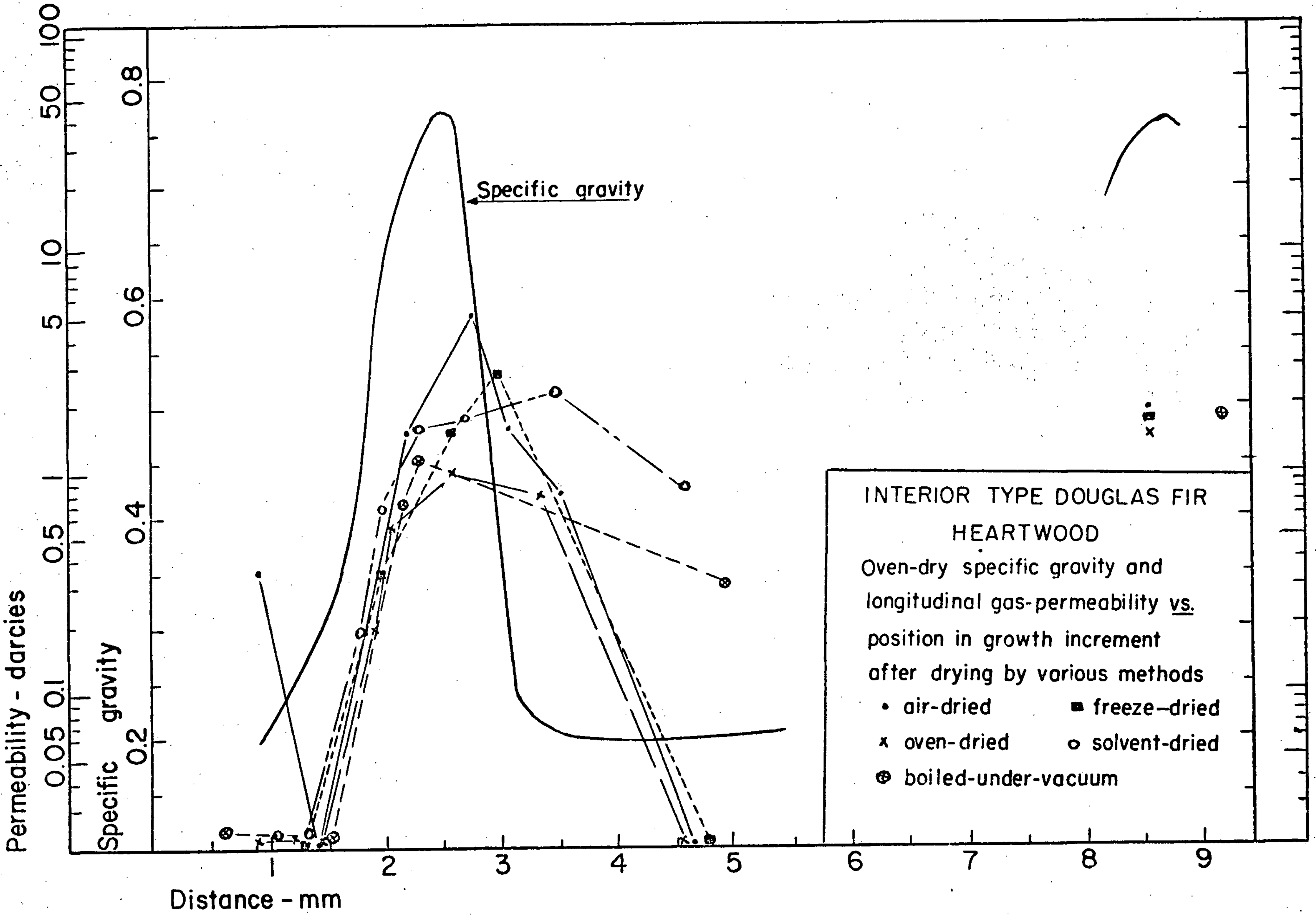

INTERIOR TYPE DOUGLAS FIR
HEARTWOOD
Oven-dry specific gravity and
longitudinal gas-permeability vs.
position in growth increment
after drying by various methods
• air-dried
■ freeze-dried
x oven-dried
o solvent-dried
⊕ boiled-under-vacuum
Specific gravity
Permeability - darcies
Specific gravity
Distance - mm
100
50
10
5
1
0.5
0.1
0.05
0.8
0.6
0.4
0.2
1
2
3
4
5
6
7
8
9

FIGURE 9

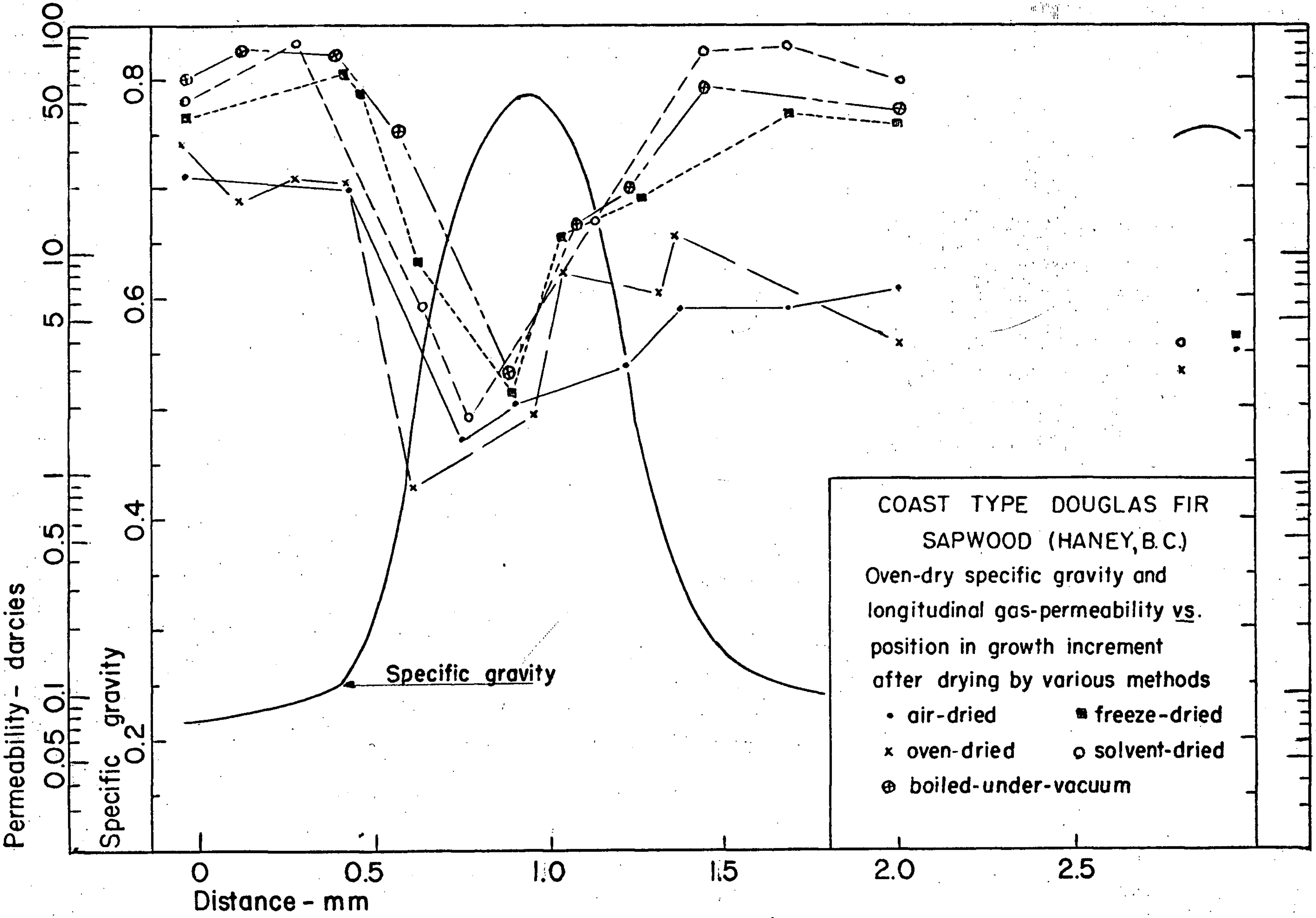

COAST TYPE DOUGLAS FIR
SAPWOOD (HANEY, B.C.)
Oven-dry specific gravity and longitudinal gas-permeability vs. position in growth increment after drying by various methods
• air-dried
■ freeze-dried
× oven-dried
○ solvent-dried
⊕ boiled-under-vacuum
Specific gravity
Permeability - darcies
Specific gravity
100
50
10
5
1
0.5
0.1
0.05
0.8
0.6
0.4
0.2
0
0.5
1.0
1.5
2.0
2.5
Distance - mm

FIGURE 10

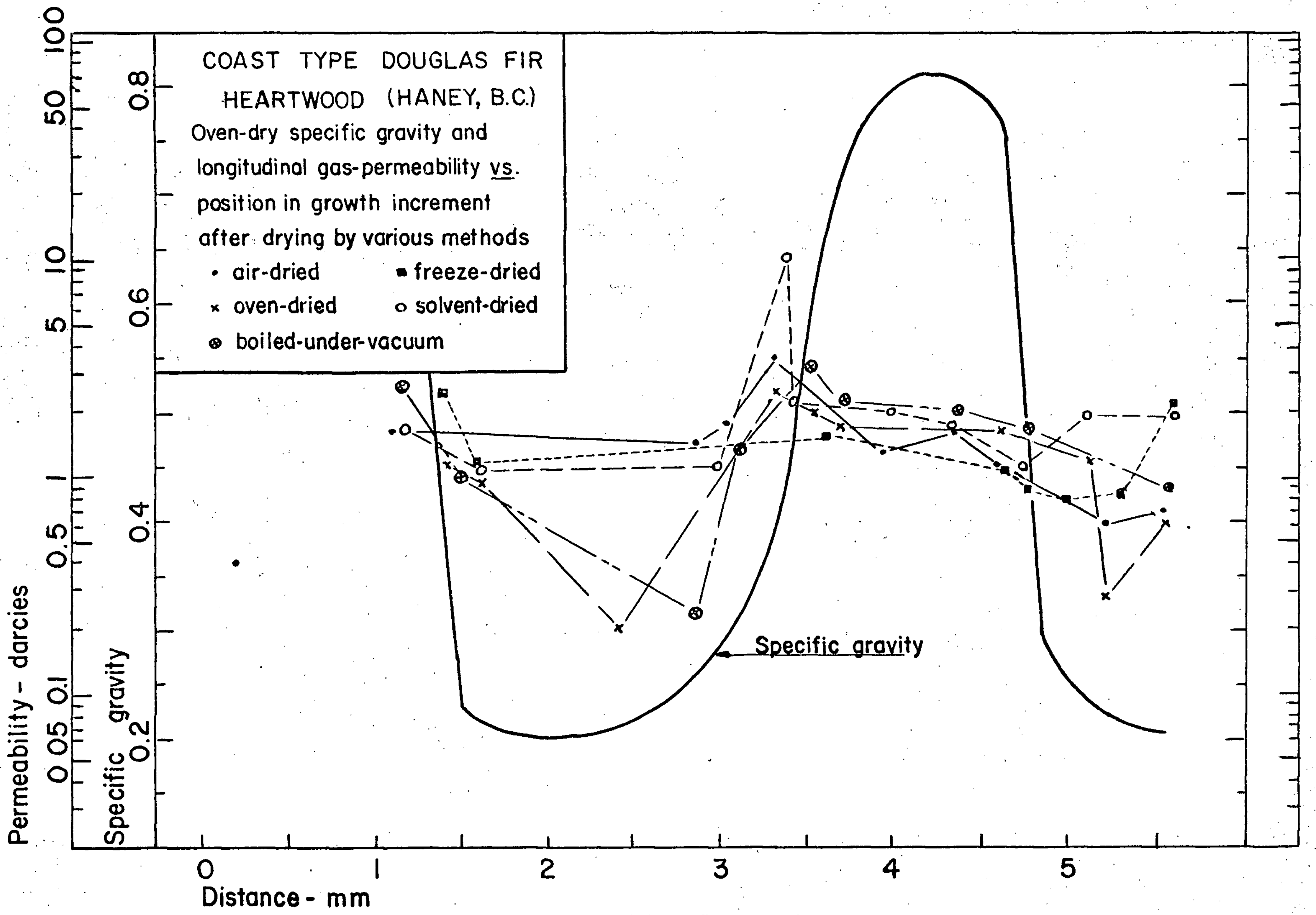
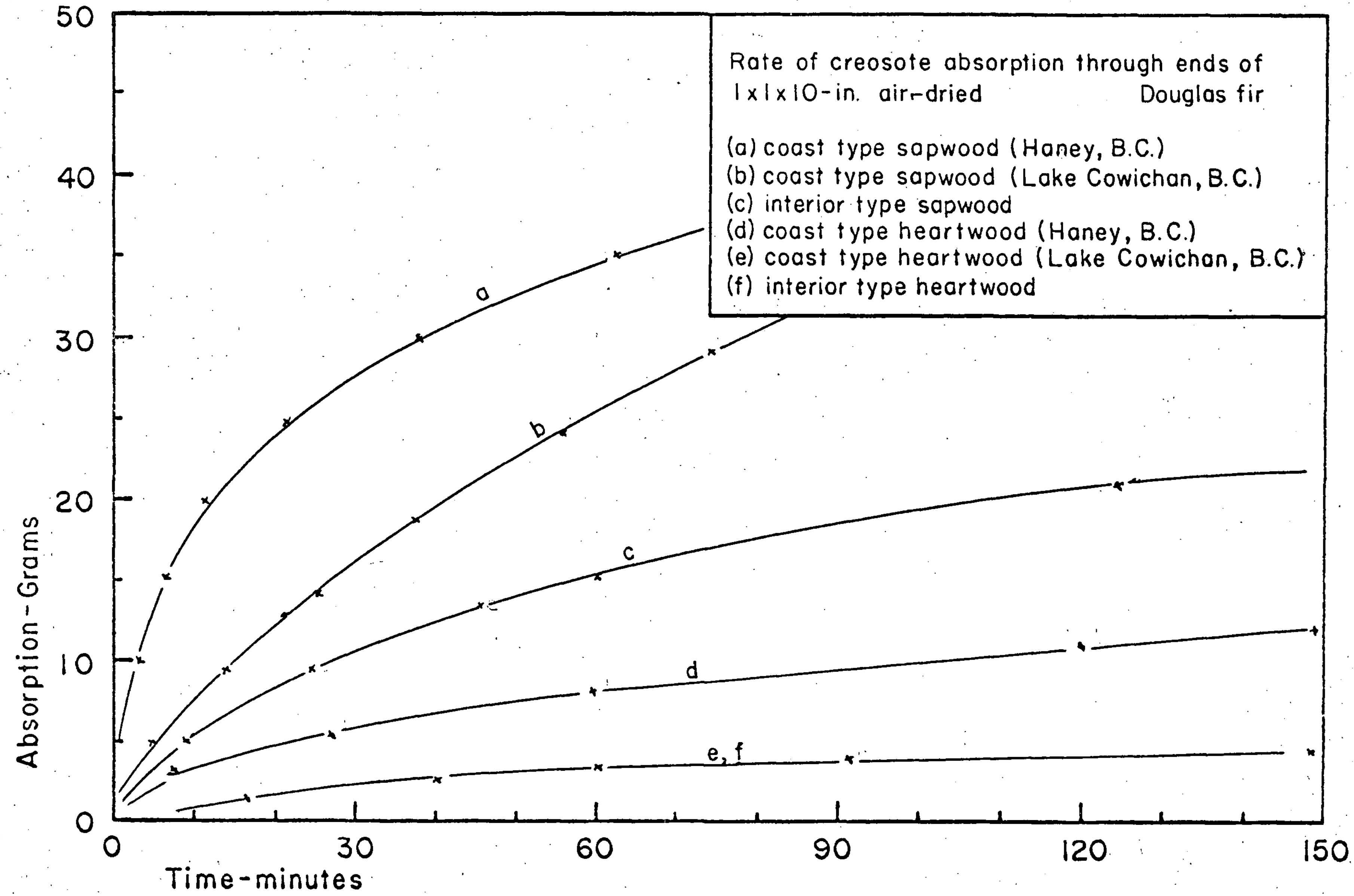

COAST TYPE DOUGLAS FIR
HEARTWOOD (HANEY, B.C.)
Oven-dry specific gravity and longitudinal gas-permeability vs. position in growth increment after drying by various methods
• air-dried
■ freeze-dried
× oven-dried
○ solvent-dried
⊗ boiled-under-vacuum
Specific gravity
Permeability - darcies
Specific gravity
100
50
10
5
1
0.5
0.1
0.05
0.01
0.8
0.6
0.4
0.2
0
1
2
3
4
5
Distance - mm

FIGURE 11



Rate of creosote absorption through ends of
1x1x10-in. air-dried Douglas fir
(a) coast type sapwood (Haney, B.C.)
(b) coast type sapwood (Lake Cowichan, B.C.)
(c) interior type sapwood
(d) coast type heartwood (Haney, B.C.)
(e) coast type heartwood (Lake Cowichan, B.C.)
(f) interior type heartwood
a
b
c
d
e, f
Absorption - Grams
Time - minutes
0
10
20
30
40
50
0
30
60
90
120
150

FIGURE 12

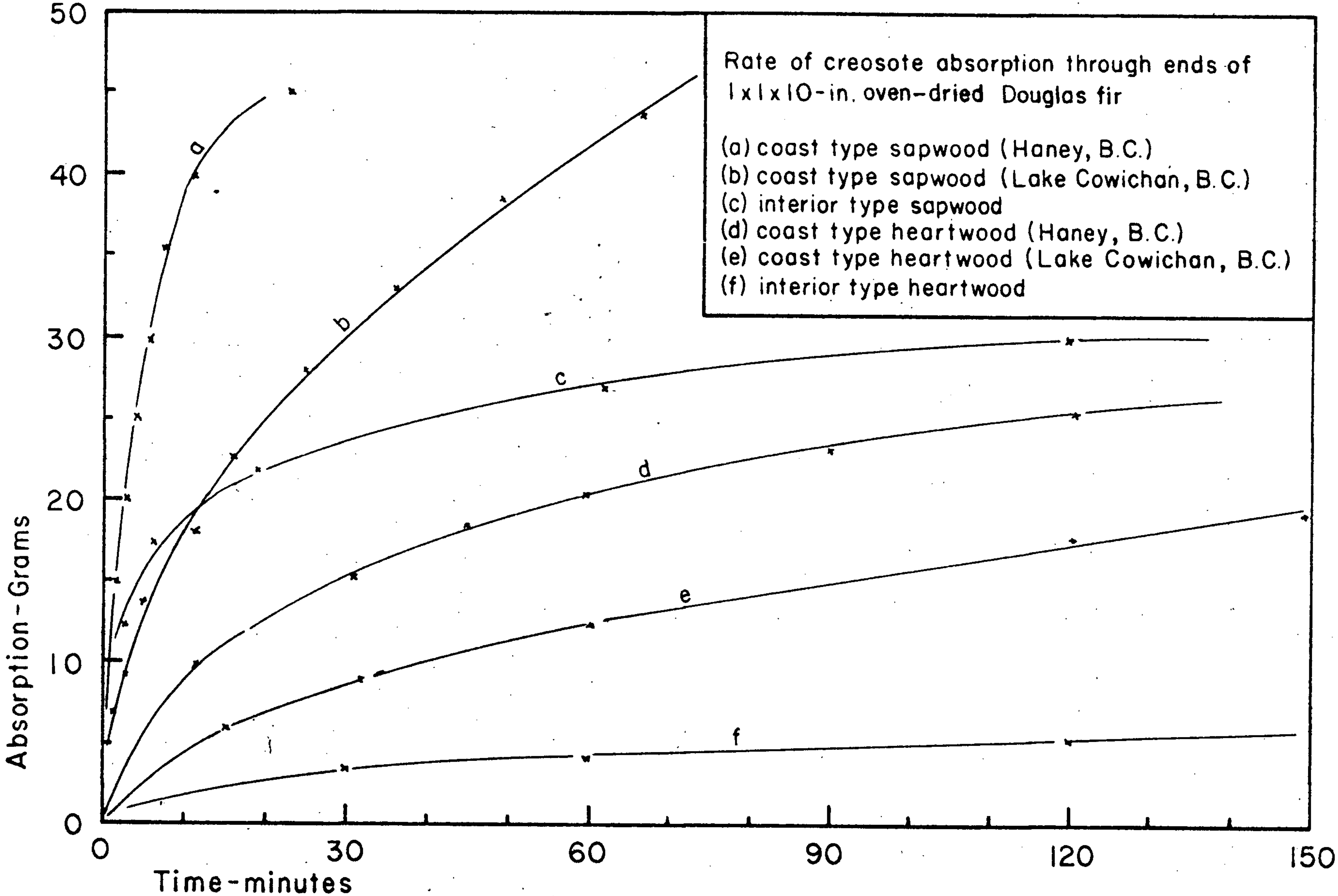
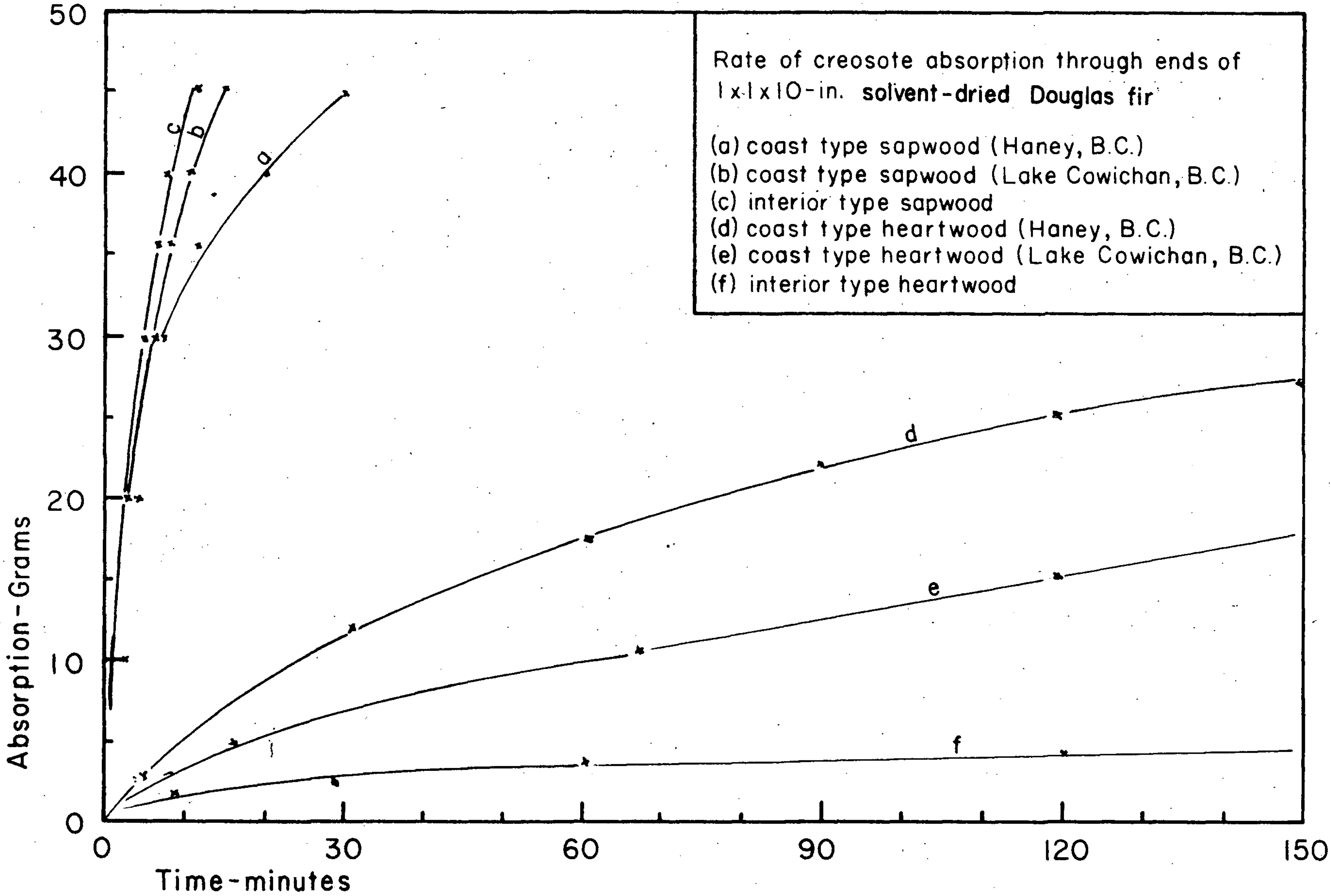

Rate of creosote absorption through ends of 1x1x10-in. oven-dried Douglas fir
(a) coast type sapwood (Haney, B.C.)
(b) coast type sapwood (Lake Cowichan, B.C.)
(c) interior type sapwood
(d) coast type heartwood (Haney, B.C.)
(e) coast type heartwood (Lake Cowichan, B.C.)
(f) interior type heartwood
Absorption - Grams
Time - minutes
0
10
20
30
40
50
0
30
60
90
120
150
a
b
c
d
e
f

FIGURE 13



Rate of creosote absorption through ends of
1x1x10-in. solvent-dried Douglas fir
(a) coast type sapwood (Haney, B.C.)
(b) coast type sapwood (Lake Cowichan, B.C.)
(c) interior type sapwood
(d) coast type heartwood (Haney, B.C.)
(e) coast type heartwood (Lake Cowichan, B.C.)
(f) interior type heartwood
Absorption - Grams
Time - minutes
0
10
20
30
40
50
30
60
90
120
150
a
b
c
d
e
f

FIGURE 14

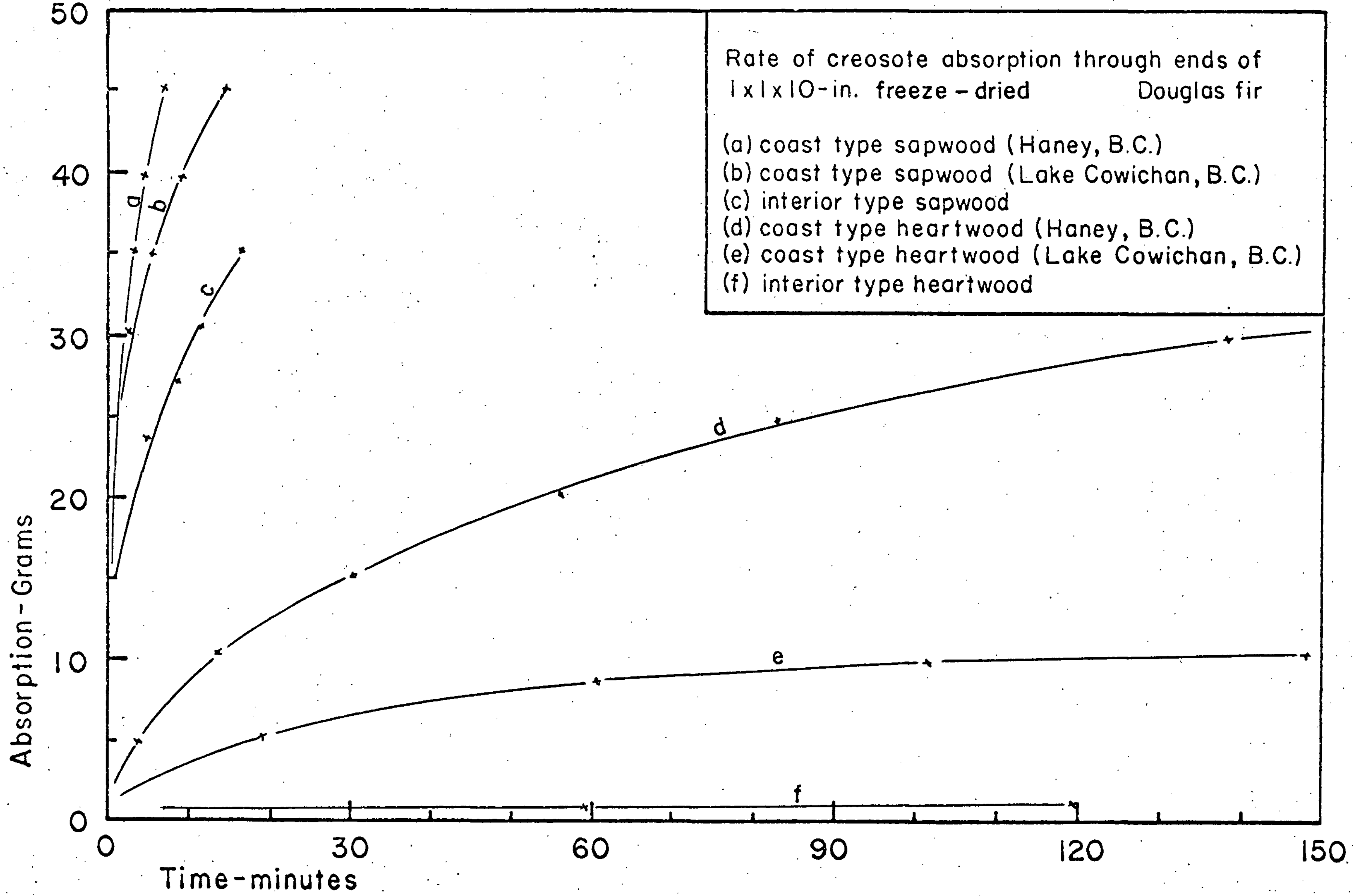

Rate of creosote absorption through ends of
1x1x10-in. freeze-dried Douglas fir
(a) coast type sapwood (Haney, B.C.)
(b) coast type sapwood (Lake Cowichan, B.C.)
(c) interior type sapwood
(d) coast type heartwood (Haney, B.C.)
(e) coast type heartwood (Lake Cowichan, B.C.)
(f) interior type heartwood
Absorption - Grams
Time-minutes
0
10
20
30
40
50
30
60
90
120
150
a
b
c
d
e
f

FIGURE 15

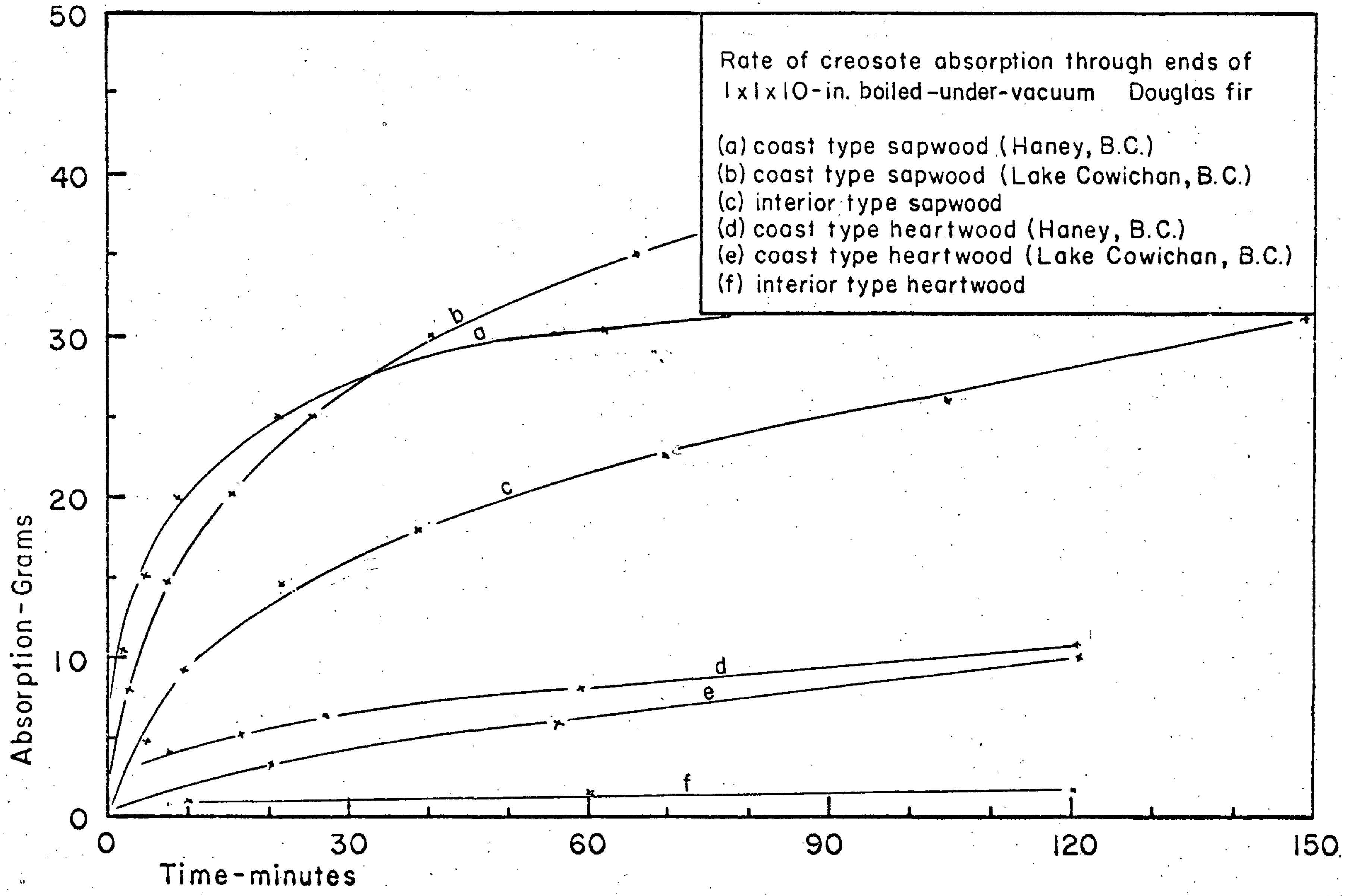

Rate of creosote absorption through ends of
1x1x10-in. boiled-under-vacuum Douglas fir
(a) coast type sapwood (Haney, B.C.)
(b) coast type sapwood (Lake Cowichan, B.C.)
(c) interior type sapwood
(d) coast type heartwood (Haney, B.C.)
(e) coast type heartwood (Lake Cowichan, B.C.)
(f) interior type heartwood
Absorption-Grams
Time-minutes
0
10
20
30
40
50
30
60
90
120
150
a
b
c
d
e
f

FIGURE 16

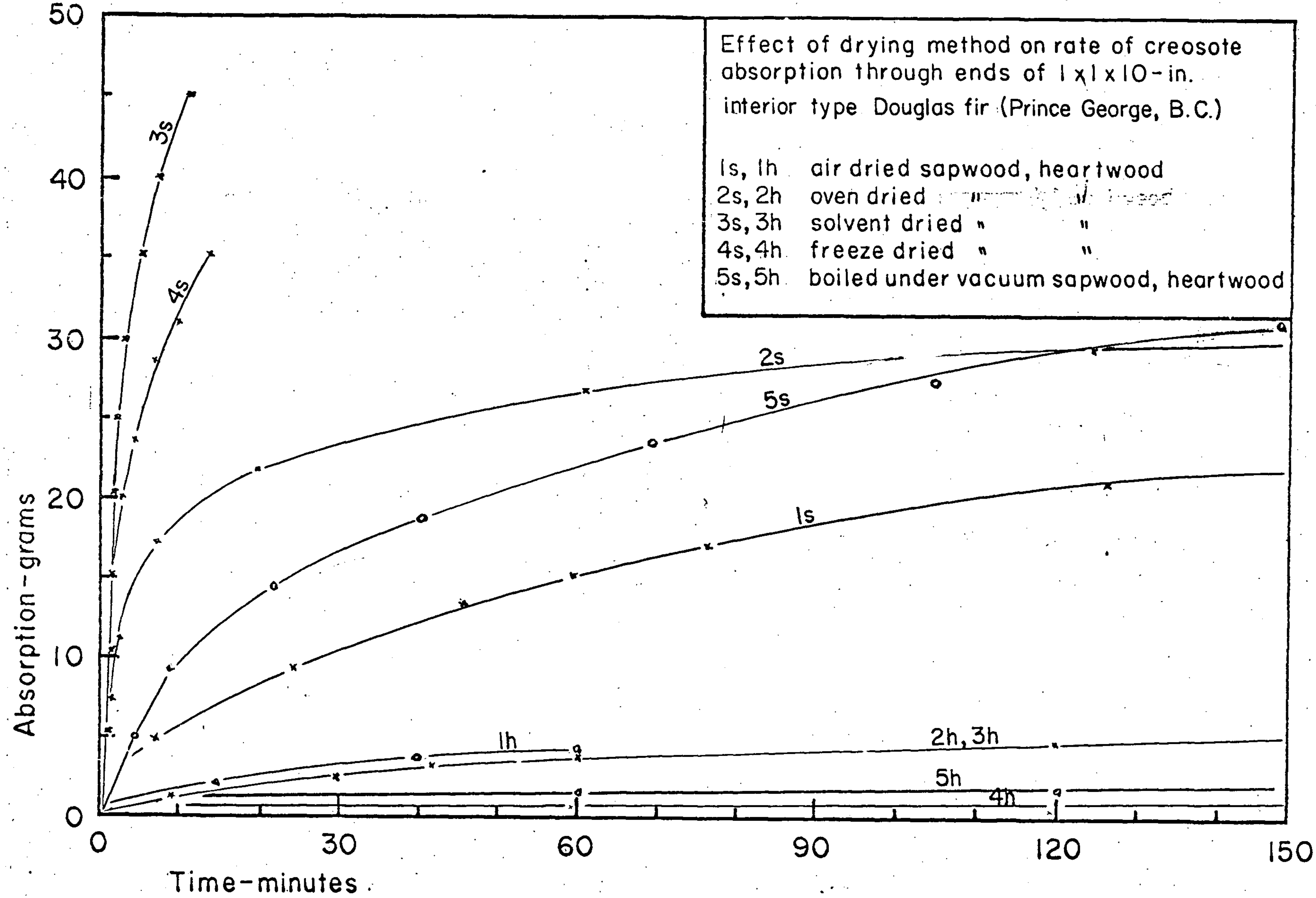

Effect of drying method on rate of creosote absorption through ends of 1 x 1 x 10-in. interior type Douglas fir (Prince George, B.C.)
1s, 1h air dried sapwood, heartwood
2s, 2h oven dried
3s, 3h solvent dried " "
4s, 4h freeze dried " "
5s, 5h boiled under vacuum sapwood, heartwood
3s
4s
2s
5s
1s
1h
2h, 3h
5h
4h
Absorption-grams
Time-minutes
0
10
20
30
40
50
0
30
60
90
120
150

FIGURE 17

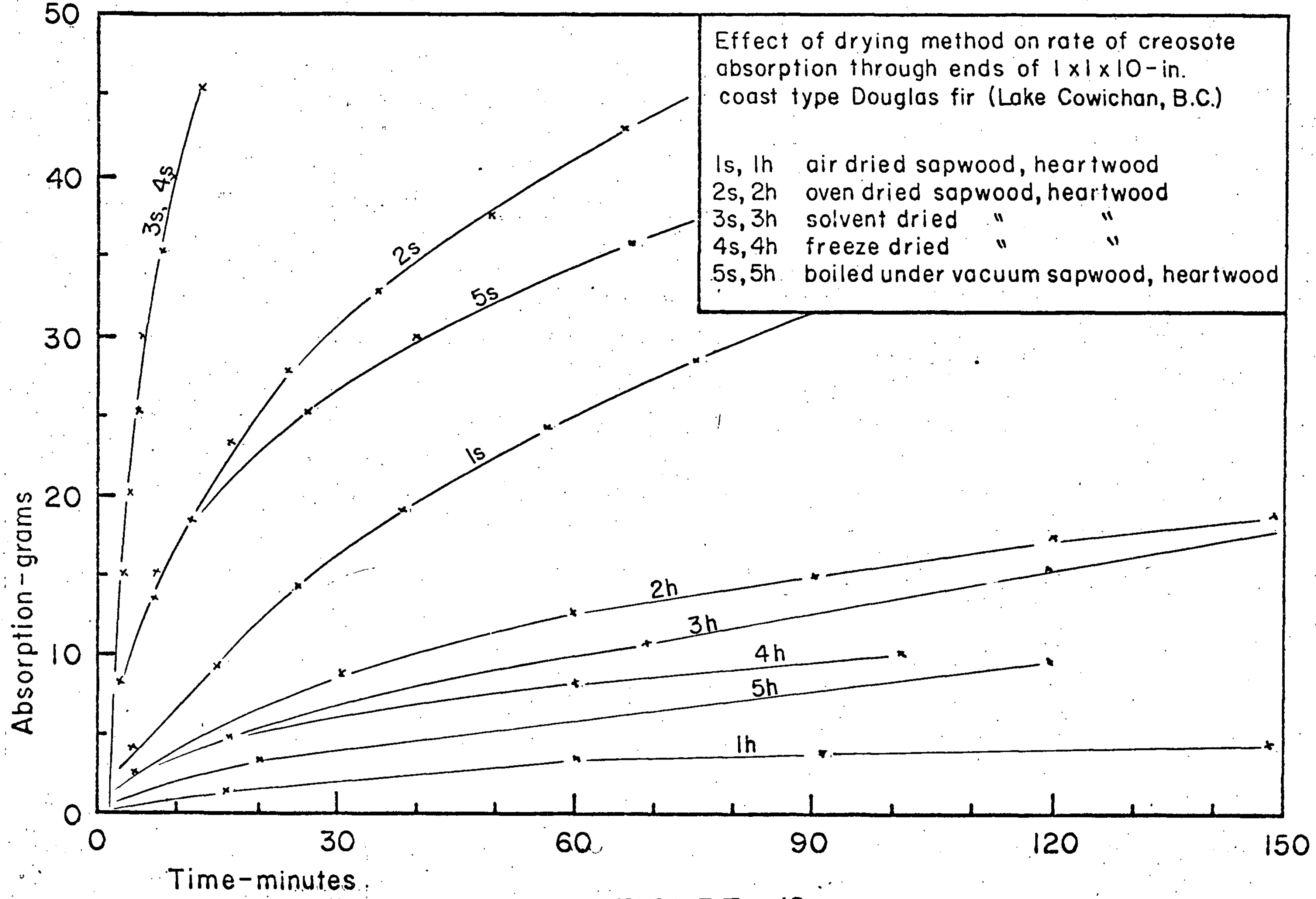
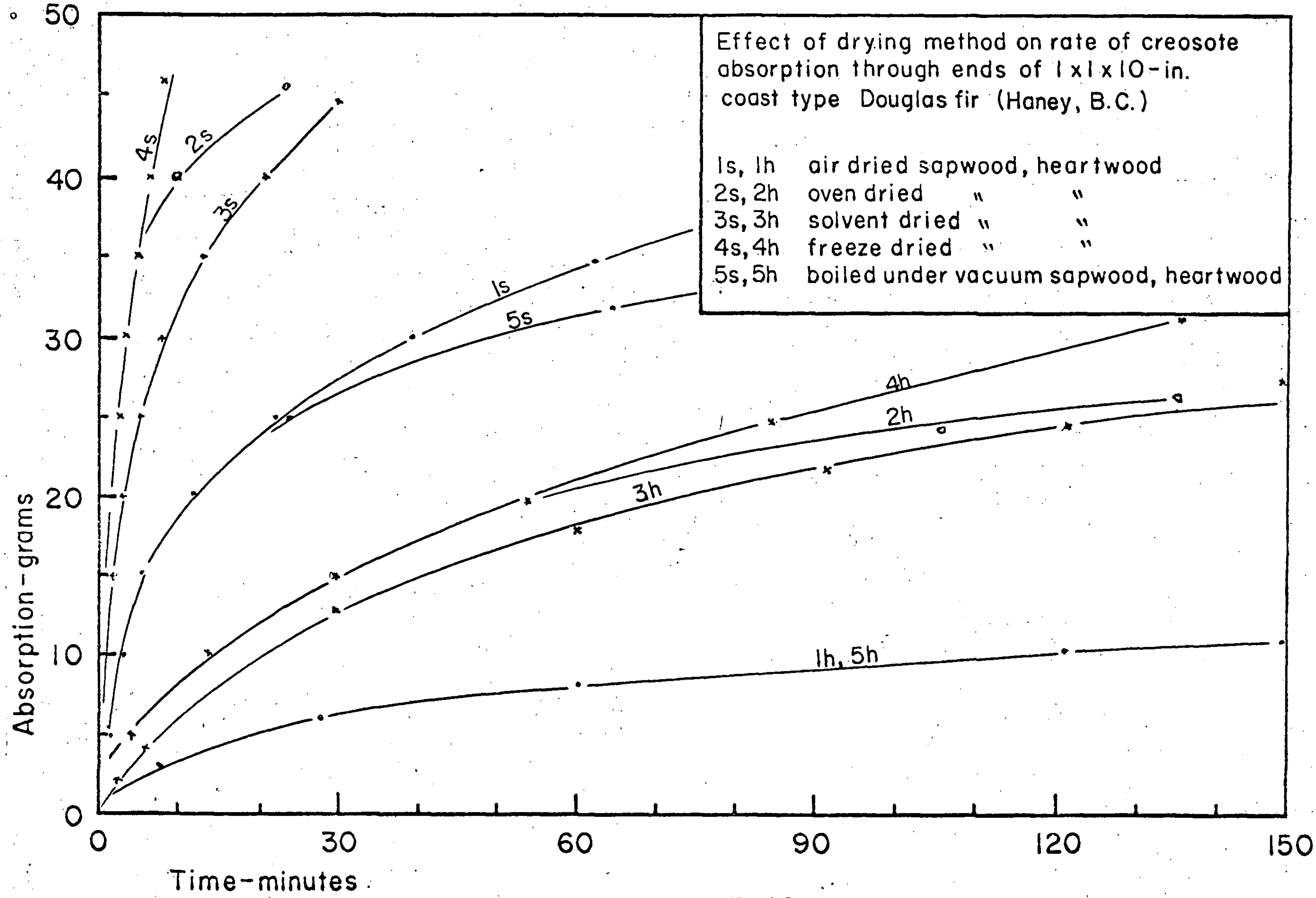
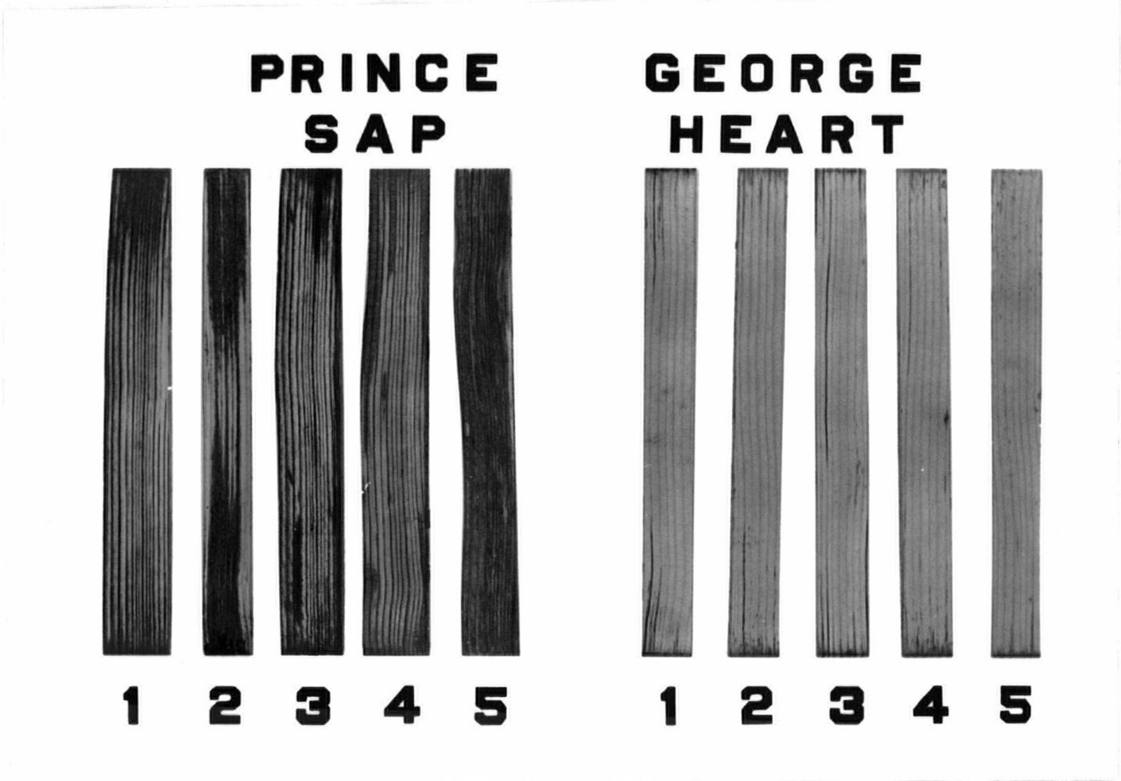

Effect of drying method on rate of creosote absorption through ends of 1 x 1 x 10-in. coast type Douglas fir (Lake Cowichan, B.C.)
1s, 1h air dried sapwood, heartwood
2s, 2h oven dried sapwood, heartwood
3s, 3h solvent dried " "
4s, 4h freeze dried " "
5s, 5h boiled under vacuum sapwood, heartwood
3s, 4s
2s
5s
1s
2h
3h
4h
5h
1h
Absorption-grams
Time-minutes
0
10
20
30
40
50
0
30
60
90
120
150

FIGURE 18

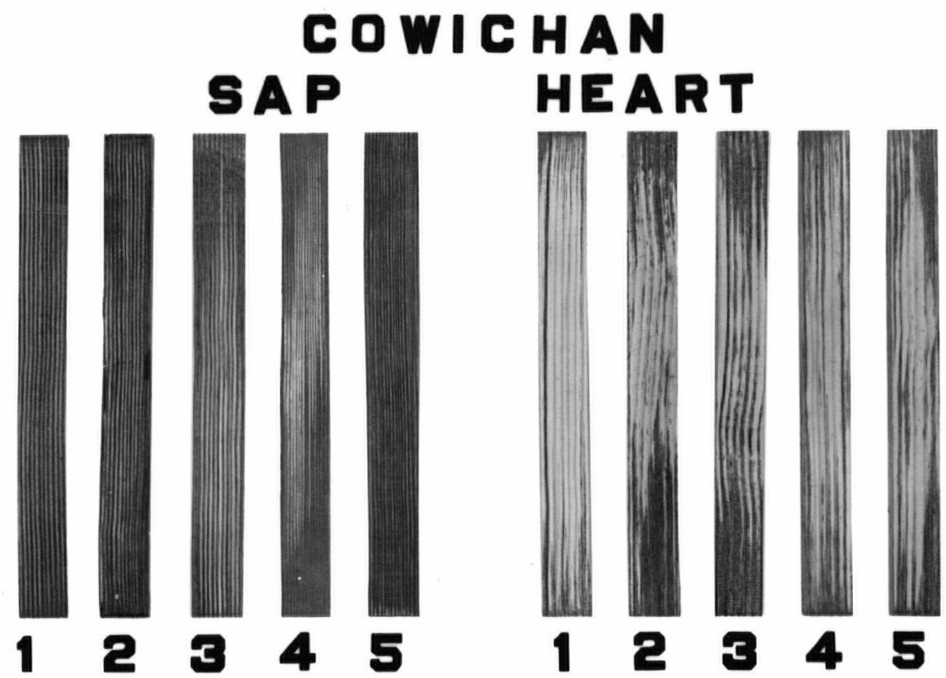


Effect of drying method on rate of creosote absorption through ends of 1x1x10-in. coast type Douglas fir (Haney, B.C.)
1s, 1h air dried sapwood, heartwood
2s, 2h oven dried " "
3s, 3h solvent dried " "
4s, 4h freeze dried " "
5s, 5h boiled under vacuum sapwood, heartwood
4s
2s
3s
1s
5s
4h
2h
3h
1h, 5h
Absorption-grams
Time-minutes
0
10
20
30
40
50
0
30
60
90
120
150

FIGURE 19



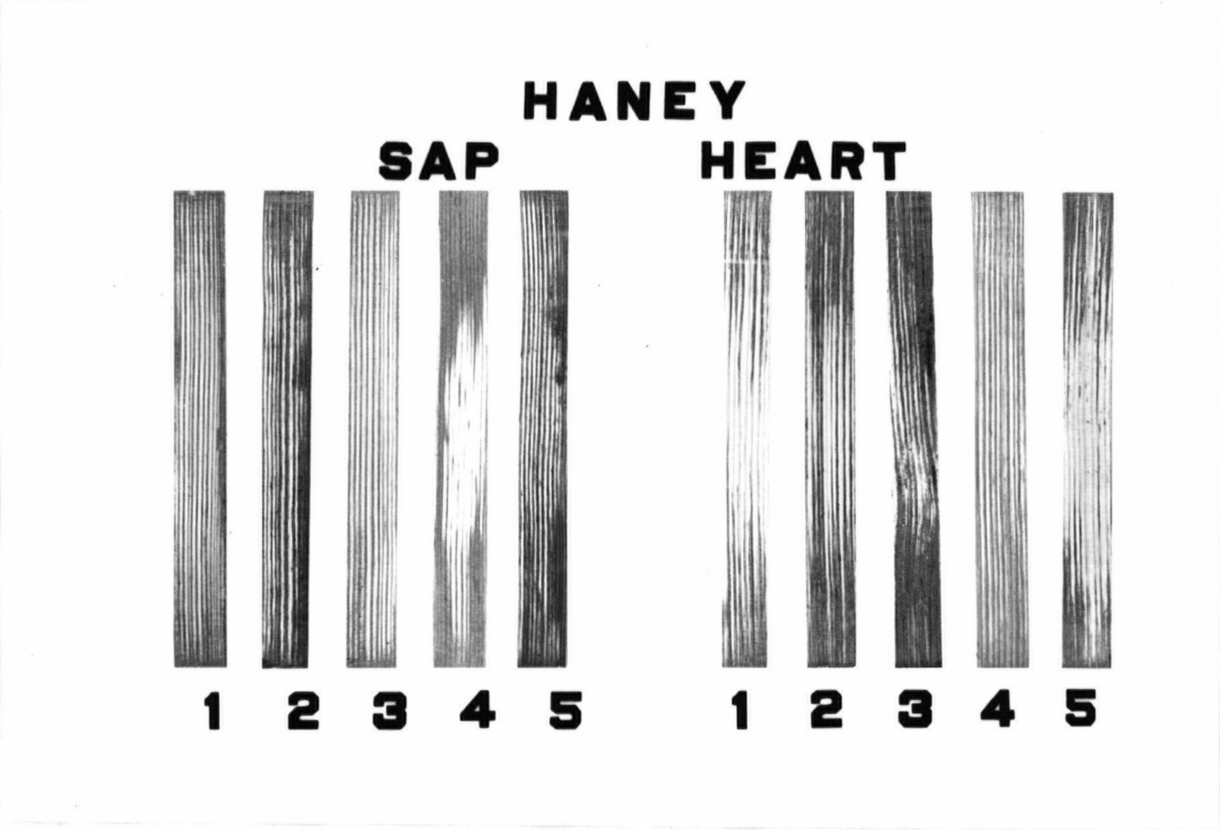
Creosote penetration of specimens, interior-type
Douglas fir
(Numbers as on page 14)
FIGURE 20



Creosote penetration of specimens, coast-type Douglas fir (Lake Cowichan, B.C.)

(Numbers as on page 14)

FIGURE 21



Creosote penetration of specimens, coast-type
Douglas fir (Haney, B.C.)

(Numbers as on page 14)

FIGURE 22