

# WATER VAPOR DIFFUSION THROUGH EASTERN HEMLOCK PERIDERM

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## ABSTRACT

Physiologically, rhytidome on the living tree has been considered a moisture barrier. It is proposed in this study that the periderm tissue in eastern hemlock inhibits radial moisture movement and may, therefore, prevent desiccation of the living secondary phloem. The kinetics of water vapor sorption by several periderm tissues were measured and compared.

Moisture movement into and through layers of thin-walled phellem and phelloderm and thick-walled phellem and phelloderm was monitored on specially prepared samples. Both phellem and phelloderm tissues are equally resistant to moisture flow. Transient diffusion coefficients determined for both thick-walled tissues were 30 times lower than those reported by others for wood and one tenth those for the thin-walled tissues for similar moisture contents.

Periderm tissues seem uniquely responsible for inhibited moisture flow in hemlock bark rhytidome with the thick-walled phellem and phelloderm most influential in this regard.

*Keywords:* Bark, rhytidome, sorption, phellem, phelloderm, *Tsuga canadensis*.

In general, tree bark consists of two major components: rhytidome and secondary phloem. All tissues within rhytidome are no longer living, while some tissues in phloem function meristematically and therefore are living.

The rhytidome functions as a protective barrier for the internal living tissues of the tree. It protects the secondary phloem and xylem from insect, fungal, or mechanical damage and physiologically acts as a thermal insulator and moisture barrier. The degree to which bark rhytidome prevents desiccation of living tissues has been demonstrated by Martin (1969). According to Martin, the moisture content of a stem decreases dramatically near the cambium. This transition zone is adjacent to the viable phloem tissues and within the innermost rhytidome. Reifsnyder et al. (1967) measured water vapor diffusion through southern pine rhytidome and determined it to be about one fourth to one eighth that of bound water diffusion in wood. However, these measurements were determined on whole rhytidome, whereas the dramatic decrease in moisture content over a very limited distance from the phloem indicates that a specific tissue within the rhytidome, rather than the entire structure, may be responsible for the apparent resistance to moisture flow.

For most conifers rhytidome consists of dead periderm and secondary phloem tissues. The secondary phloem tissues in rhytidome are remnants of the viable phloem due to the lateral growth of the tree. This tissue is predominantly made of expanded parenchyma cells and collapsed sieve cells. The periderm cells are generated within the phloem from the meristematic tissue called phellogen. Phellogen in turn produces phellem cells to the outside and phelloderm cells to the inside of the tree as shown for conifers in Fig. 1. Several layers of phellem and phelloderm cells adjacent to the phellogen are thick-walled and appear together with the phellogen as irregular tangential bands within the rhytidome, which in

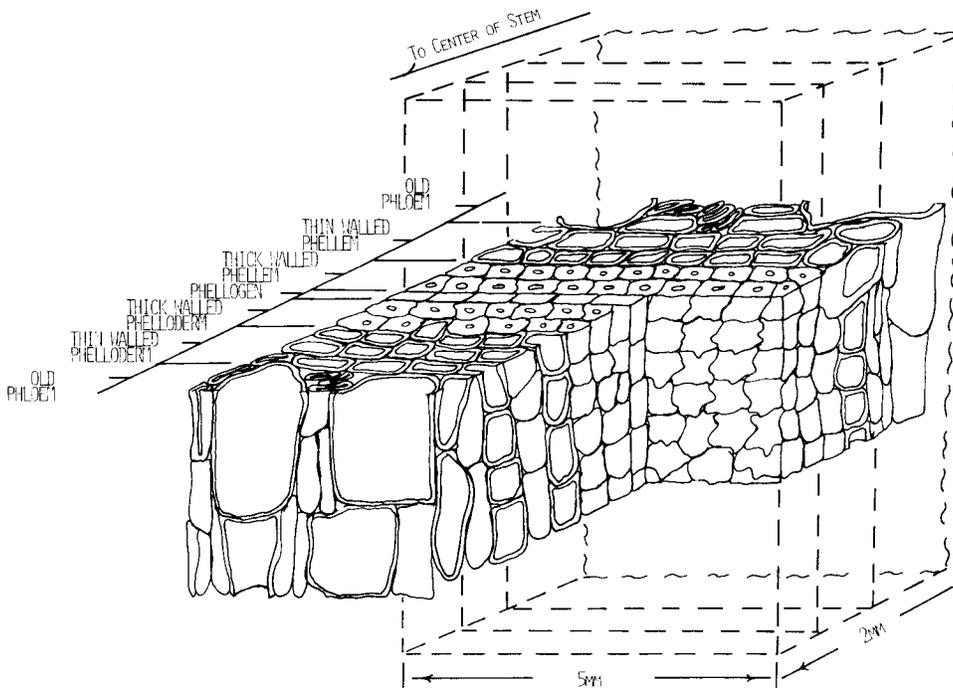


FIG. 1. Schematic representation of coniferous bark periderm tissues.

living tissues are observed to be light-colored. In most coniferous bark, thin-walled phellem and phelloderm cells lie adjacent to the respective thick-walled tissue. Srivastava (1964) and Howard (1971) have stated that it is probably the thin-walled phellem cells that are specifically resistant to moisture movement. The basis for this assertion is the absence of pits and the presence of suberin—an inert hydrophobic polyester of aliphatic and aromatic acids. Crist (1972), however, believes that the thick-walled phellem cells may play an important role in inhibiting moisture flow. They are highly lignified, and contain few intercellular spaces. According to Crist, many conifer barks contain little suberin, and some lack any thin-walled phellem cells.

The objective of the investigation reported here is to determine to what extent eastern hemlock (*Tsuga canadensis*) rhytidome inhibits moisture flow, and, to determine to what extent a specific periderm tissue or tissues may be responsible.

#### MATERIALS AND METHODS

Eastern hemlock rhytidome was chosen because its anatomical structure is well suited for making the test specimens used in this study. Specimens were removed from living trees and conditioned to equilibrium at 26 C and 60% RH.

Diffusion coefficients for water vapor sorption were determined for four specimen types. The four systems were designed such that the moisture movement through thick-walled phellem, thin-walled phellem, thick-walled phelloderm, and thin-walled phelloderm could be measured independently and compared. Each

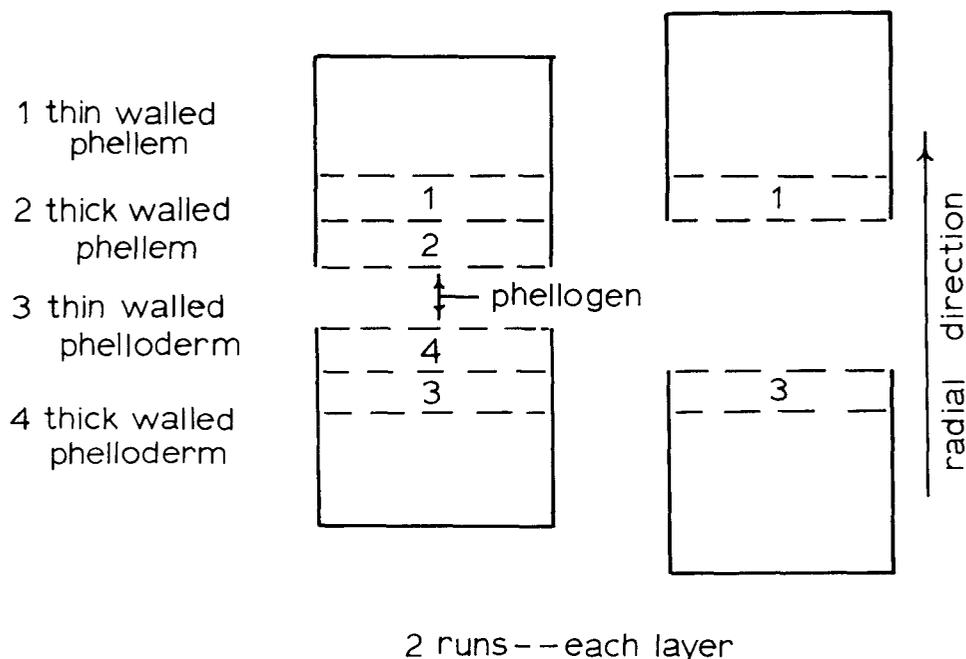


FIG. 2. Schematic diagram of specimen cross sections used in the sorption experiment showing the location of tissue layers.

were replicated once to compare periderm tissue near the cambium (Type A) with tissues over three periderm layers distant (Type B).

Homogeneous tangential surfaces of thick-walled phellem and phelloderm are readily prepared by splitting rhytidome sections along phellogen layers with a knife. Phellogen cells are thin-walled and form readily cleaved planes. Small flat specimens were excised with a scalpel from both the phellem and phelloderm sides. Care was taken not to damage the periderm surface. All specimens were sanded to a 1-cm length, 5-mm width, and 2-mm thickness. In all cases across the 2-mm thickness, only one periderm layer is permitted. The remaining portion of the specimen consisted of phloem tissues and residual thin-walled periderm from the succeeding periderm layers. To clarify the excising procedure, the broken lines in Fig. 1 represent a specimen removed from the rhytidome. Notice the relative layering of the thick- and thin-walled tissues within the specimen. Tissue layers in the cross section of specimens used in these experiments are schematically shown in Fig. 2. Note that certain specimens contain thick- and thin-walled tissue faces and others only thin-walled tissue faces: one each of phellem and phelloderm. After conditioning, a small hole was placed in an end of the specimen through the 2-mm thickness. The specimens were weighed, a wire hook was inserted into the specimen, and to five sides, two coats of a two-component epoxy adhesive were applied. When all six sides of similar samples were coated and external vapor pressure was altered, no observable change in moisture content was detected. Therefore, after coating five sides, moisture can move into the rhytidome section only through the exposed surfaces that were either thick-walled

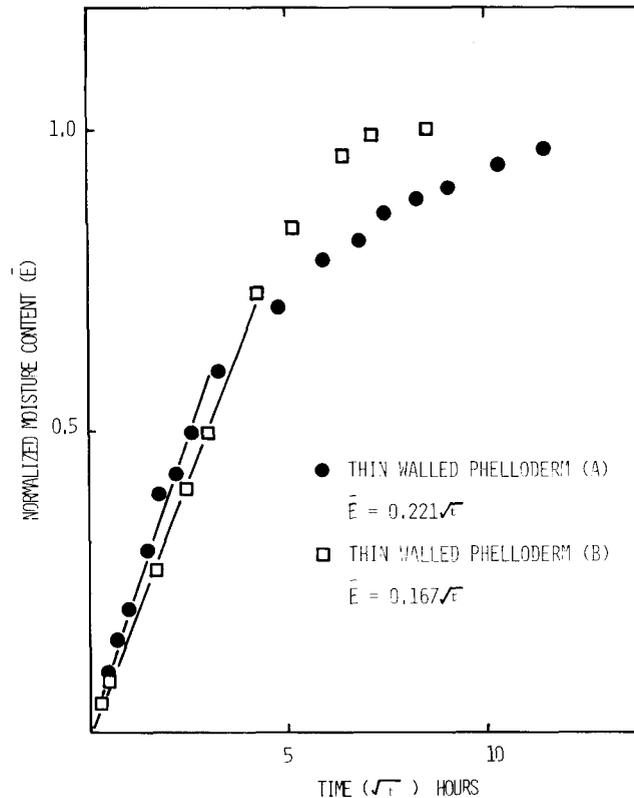


FIG. 3. Average fractional change in moisture content ( $\bar{E}$ ) as a function of time for new (A) and old (B) thin-walled phellogen tissues.

phellem and phelloderm or thin-walled phellem and phelloderm. The specimens were reweighed to determine the weight of wire and epoxy added. Four specimens at a time, one of each exposed surface, were placed in a quartz spring vacuum apparatus. Constant temperature water baths maintained a testing temperature of 25 C. Moisture loss and pickup were determined gravimetrically by observing the extension of quartz springs through a cathetometer. Adsorption experiments were performed over saturated aqueous solutions of ammonium phosphate (95% RH at 25 C) in a vacuum. Initial moisture contents of all specimens were about 7–9%. After equilibrium was attained in the vacuum apparatus, and the test complete, specimens were oven-dried to determine moisture content.

For short time intervals (i. e., characteristic time  $\tau$  less than 0.2) the diffusion coefficient ( $D_g$ ) can be calculated according to Siau (1971)

$$D_g = \frac{(\bar{E})^2 L^2}{5.10t}$$

where  $L$  is the length of unidirectional moisture flow,  $t$  is the time,  $\bar{E}$  is the fractional change in average moisture content and  $(\bar{E})^2/t$  is the square of the slope determined by a linear regression analysis at short times (i. e., at or below half the time to equilibrium). It is assumed that  $D_g$  is constant over a small moisture

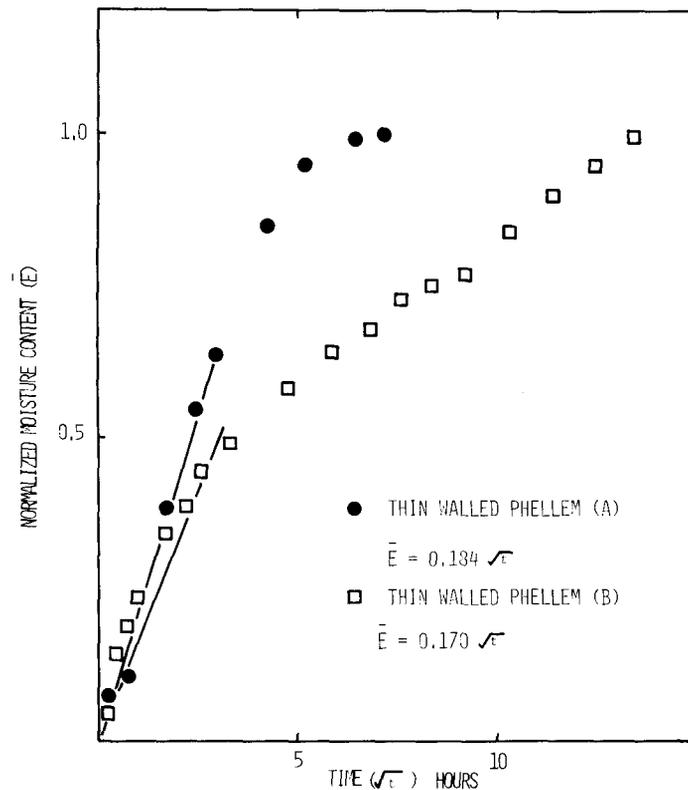


FIG. 4. Average fractional change in moisture content ( $\bar{E}$ ) as a function of time for new (A) and old (B) thin-walled phelloderm tissues.

content range, and that the relative capacity to hold moisture of the tissues in the specimens studied is similar.

#### RESULTS AND DISCUSSION

All specimens tested equilibrated at moisture contents between 26 and 28%, similar to the moisture contents reported by Martin (1969). No relationship between these small differences in final moisture contents and the specimen types studied could be determined. The capacity of hemlock bark for water vapor is similar also to that generally reported for wood. The relative change in moisture content and the moisture content at equilibrium are assumed the same for all tests.

Figures 3 and 4 are plots of normalized moisture content  $\bar{E}$  as a function of square root of time for thin-walled tissue. The lines represent linear regressions. The regression equations shown are the results of a least squares best fit of the data forced through the graphical origin. The shape of the data plots is similar to those reported for wood with an initial linear region followed by a gradually retarded sorption and finally equilibrium. The time to equilibration varies considerably, but does not seem to be related to the cell tissue type or the distance of the periderm layers from the cambium. The relative slopes determined by regres-

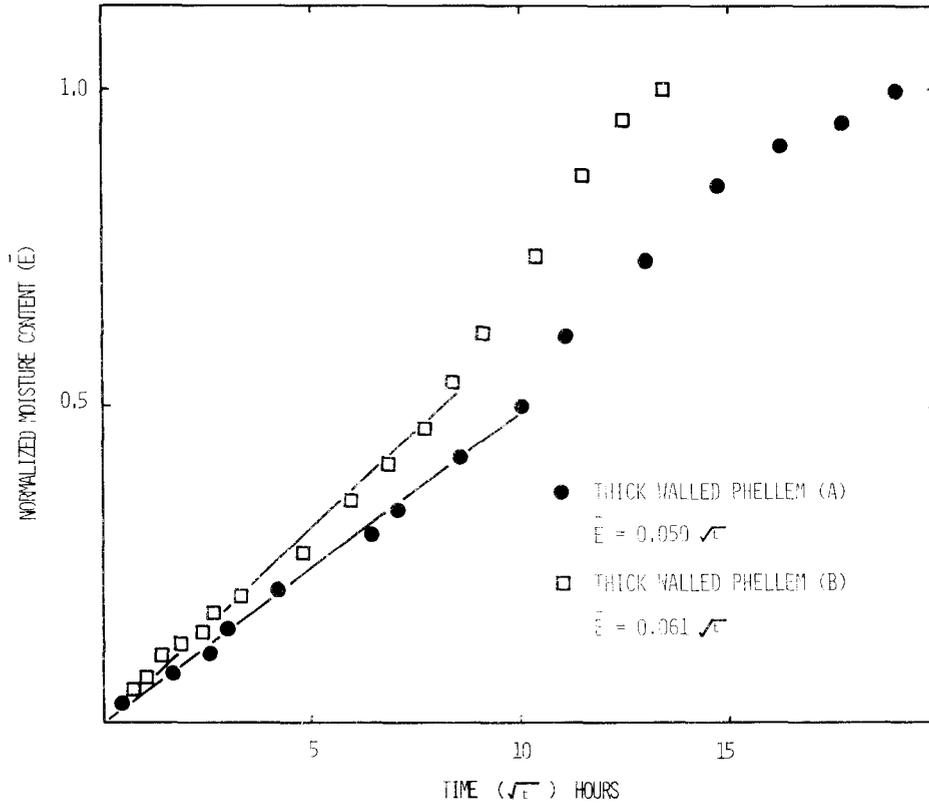


FIG. 5. Average fractional change in moisture content ( $\bar{E}$ ) as a function of time for new (A) and old (B) thick-walled phellem tissues.

sion are similar for all thin-walled tissues. These tissues respond in a like manner during initial adsorption.

Figures 5 and 6 are plots of normalized average moisture content  $\bar{E}$  as a function of the square root of time for moisture movement through thick-walled tissues. The lines are the result of regression analysis during initial adsorption. The functions shown are the results of forcing the regression through the graphical origin. The slopes are again very similar, but about one third of those found in Figs. 3 and 4 for thin-walled specimens. The time to equilibrium varies, however: the thick-walled phelloderm and phellem farthest from the cambium equilibrate in half the time (i.e., 170 and 195 h vs. 360 and 400 h) of the younger tissues.

TABLE I. Diffusion coefficients for periderm tissues of eastern hemlock (*Tsuga canadensis*).

	Phelloderm		Phellem	
	A	B	A	B
	(Cm <sup>2</sup> /sec × 10 <sup>-5</sup> )			
Thick-walled	0.280	0.516	0.284	0.288
Thin-walled	4.780	2.912	3.376	2.828

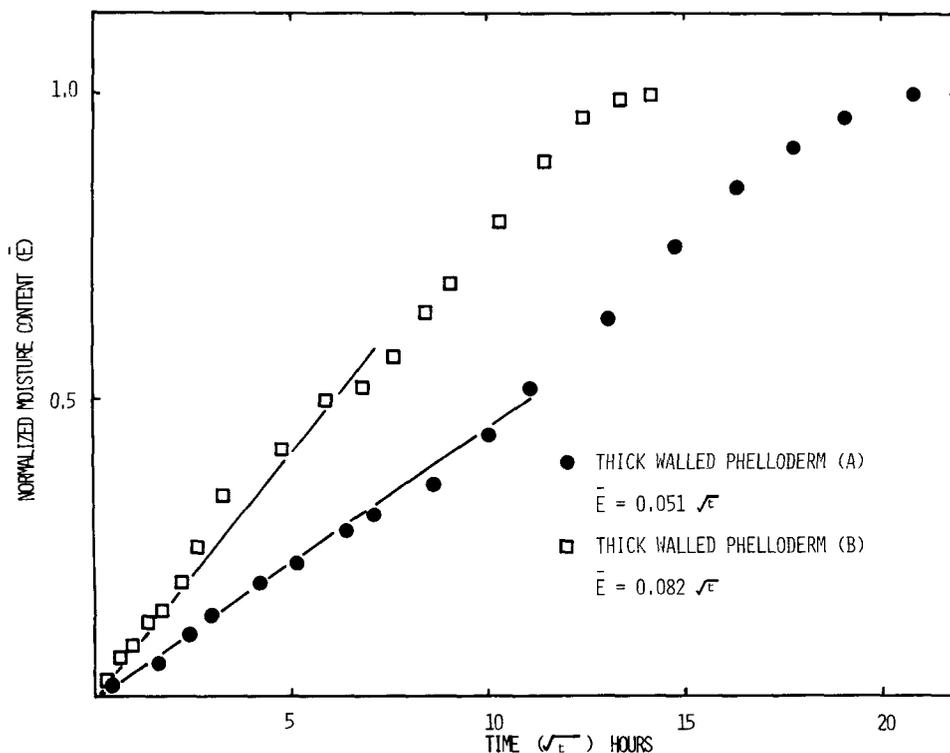


FIG. 6. Average fractional change in moisture content ( $\bar{E}$ ) as a function of time for new (A) and old (B) thick-walled phelloderm tissues.

The plots all have a similar shape. Adsorption up to about 16 h is followed by a slightly retarded rate, which in turn is followed by a gradually increasing sorption rate to equilibrium. All curves are somewhat concave to the time axis. It seems the diffusion rates for water vapor differ for the thick-walled cells and the thin-walled cells. The more rapid adsorption rates of the thin-walled tissue shown in Figs. 3 and 4 may influence the adsorption at long times for the thick-walled specimens, causing this unusual curvature. Figures 5 and 6 appear to be composites of the relative rapid adsorption of the thin-walled cells at long times, and the retarded adsorption of the thick-walled tissues at short times.

Table 1 contains the calculated diffusion coefficients for the eight specimens tested. For thin-walled tissues, these are about one third of those reported by Siau (1971) for bound water diffusion in wood. Thick-walled coefficients are about one tenth those determined for the thin-walled tissue. No significant differences are noted between phelloderm and phellem tissues, nor between tissue at different distances from the cambium (Type A vs. Type B). Periderm tissues prevent the desiccation of the living stem. Phelloderm and phellem are equally important in this regard, however, the thick-walled tissues of both are most effective. Further, because of the layering of the periderm within the rhytidome, the effectiveness of all tissues in inhibiting radial moisture movement is additive and probably dependent on the number of layers present.

## SUMMARY AND CONCLUSIONS

The rhytidome of eastern hemlock (*Tsuga canadensis*) bark prevents the desiccation of the living stem. Sorption rate measurements on rhytidome samples indicate that bark periderm is responsible for retarded moisture flow radially from the stem. Adsorption rates for thick-walled and thin-walled phellem and phellogen periderm tissues are slower than those reported by others for xylem. Both thin-walled tissues sorb at one third the rate of wood. Specimens containing thick-walled phellem and phellogen act as a layered system with tissue of two distinct sorption rates. Rhytidome samples containing one layer of thick-walled tissue sorb at one thirtieth the rate reported for wood. These uniquely hydrophobic tissues and the additive effect of cumulative periderm layering within the rhytidome found in many tree barks, make it a very effective moisture barrier.

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