fiber on muscle fiber has so far proved consistently maximal.

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A NEW TECHNIQUE IN TREE MEDICATION FOR THE CONTROL OF BARK BEETLES[1]

THE possibility of injecting chemicals into the sap stream of living trees in order to inhibit the action of parasitic organisms or correct some pathological condition has appealed to botanists and entomologists for a number of years. Variations of this method of control have likewise been utilized by so-called "tree doctors" to reap no inconsiderable return from unsuspecting owners of valuable shade trees, usually without accomplishing the desired results. A number of valuable contributions in this field and on related subjects have been made as a result of careful experimental work.[2] That it is possible to introduce fluids into the sap stream has been conclusively demonstrated, but in most cases the results have been of limited practical value. This is because usually these substances are not well distributed through all portions of the tree. Good distribution, even to the leaves, has been reported in those portions of the tree in direct communication with the point of injection, but the lateral dissemination has usually been slight.

In the summer of 1925, following the publication of results obtained by Lipman and Gordon,[3] the writers and Mr. J. A. Beal at Asheville, North Carolina, attempted to use the method therein described to destroy the developing broods of the southern pine beetle (*Dendroctonus frontalis* Zimm.) in shortleaf pine. It might be explained here, in reference to this insect, that these beetles attack the trees simultaneously in great numbers, bore through the bark and in about ten to fifteen days completely girdle the inner phloem and at the same time introduce blue-stain.[4] The trees after attack are necessarily doomed and, for the objective at hand, there was no effort made to save them. It was desired merely to kill the developing broods under the bark and thus prevent their escape and attack of other living trees. The control practices now in use for the bark beetles of the genus Dendroctonus consist in felling the tree and either peeling or burning the bark of the entire tree or other practices that destroy the broods, at a cost ranging from 75 cents to $5 per tree, depending on the size. It was hoped that these costs for treatment might be greatly reduced by some such method as that described.

Work was continued through 1926, 1927 and 1928. The results obtained were very conflicting. A high percentage of brood mortality occurred in some trees and with some chemicals, but in general the insects were killed only in a narrow strip above the point or points of injection. It was obvious that the idea might be practical but that the technique was poor; in other words, more thorough lateral distribution of the chemical was needed.

In the meantime several patents had been issued describing various methods of obtaining complete distribution of dye or preservatives in the tree. These were all too elaborate and expensive for the purposes intended. It occurred to the senior author that a combination of the technique already in use and the ringing practice used by orchardists to stimulate the setting of fruit buds might be more effective. Accordingly, during the summer of 1929 approximately two hundred trees were treated by the authors and R. W. Caird, the latter working chiefly on the physiological aspects of the problem.

The technique adopted was as follows.

(1) At a convenient working distance near the base of the tree the bark is first smoothed completely around the tree by the use of a wood rasp or draw knife to such a degree that it will permit a water-tight application.

(2) The next step consists in making a narrow (one eighth to one fourth inch) incision or notch completely around the circumference of the tree, by means of a saw or sharp knife, through the bark, and through two or more annual layers of wood, or through the entire sapwood, depending on the depth of penetration desired. This incision is located on that portion of the bark which has been smoothed.

(3) On one side of the tree an auger hole about

[1] Publication of the results obtained by the Bureau of Entomology at this time while the investigations are still in an experimental stage seems justified largely because a technique appears to have been developed which has some advantage over those previously described. It should be distinctly understood, however, that the Bureau of Entomology is not at this time advocating the use of this method for general application in the control of insects.

After this article had been prepared, Dr. Caroline Rumbold called our attention to the use of a somewhat similar technique by M. A. Boucherie, "Mémoire sur la conservation des bois," *Annales de Chimie et de Physique,*" 74: 113–157, 1840.

[2] J. Davidson and H. Henson, "The Internal Condition of the Host Plant in Relation to Insect Attack, with Special Reference to the Influence of Pyridine," *Ann. Appl. Biol.*, 16: 458–471, 1929; A. Muller, "Die innere Therapie der Pflanzen," Monograph angew. Ent. 8, pp. vi–206, illus., 1926 (abstract in *Rev. Appl. Ent.*, 14, Ser. A: 505); C. T. Rumbold, "The Injection of Chemicals into Chestnut Trees," *Am. Jour. Bot.*, 7: 1–20, 1920.

[3] C. B. Lipman and A. Gordon, "Further Studies on New Methods in the Physiology and Pathology of Plants," *Jour. Gen. Physiol.*, 7: 615–623, 1925.

[4] F. C. Craighead, "Interrelation of Tree-Killing Barkbeetles (Dendroctonus) and Blue Stains," *Jour. Forestry*, 26: 886–887, 1928; R. M. Nelson and J. A. Beal, "Experiments with Blue-stain Fungi in Southern Pines," *Phytopathology*, 19: 1101–1106, 1929.

one half inch in diameter and centering on the notch is bored into the tree to a depth of about one inch.

(4) Two methods have been used for making a water-tight connection around the tree. A strip of rubber band about two inches wide, such as old inner tubing, is stretched around the tree covering the notch and placed preferably so as to overlap at the point where the one half inch auger hole is bored. This bandage can be held by several nails or by wire tourniquets above and below. The other method consists in the use of an impervious plastic putty or waxlike material (grafting wax, asphaltum paste or tree gums) that will adhere readily to the bark. This method has advantages on trees of irregular circumference. Grafting wax has proved to be the most practical material tried.

(5) At a convenient distance, a few inches to a foot or more above the incision, a container is hung on the tree for the purpose of holding the liquid to be injected into the tree. This container is connected to the notch by means of a short section of rubber tubing terminating in a piece of metal pipe about one fourth inch in diameter. This pipe making contact with the container is connected to the circumferential notch through the one half inch auger hole and sealed by the plastic material used or by pushing it through the rubber bandage around the notch.

By means of this technique, from two quarts to several gallons of liquid, depending on the quantity required, can be injected into the tree in a few hours and thorough distribution obtained through all the outer annual rings severed and to the topmost branches and leaves. Two quarts was ample in most cases on the relatively small trees used. The quantity varies, depending on the concentration of chemicals employed and size of tree treated.

In general, the results were most encouraging. Complete brood mortality was obtained in practically all cases with certain chemicals, provided the application was made before the sapwood became blue-stained by associated fungi[4] and the ascending sap stream disturbed. The following table summarizes a few of the materials used, the quantities and the results obtained.

Although the writers have made no attempts to use dilute solutions with the idea of killing the insects and saving the tree, it is within the realm of possibility that with sufficient experimentation this objective could be attained. In the case of trees (conifers) that are more susceptible to this girdling of the cambium two or more breaks in the notch can be left on the circumference, which will greatly accelerate subsequent healing,[5] and the notches connected with a drill, or an additional container or attachment used with each notch. With most hard-woods the narrow saw cut completely encircling the tree will not cause death, but with conifers over 50 per cent. of the trees so treated as checks died.

Some tests have been made on the possibilities of utilizing this process for the injection of wood preservatives into the sapwood before felling the tree. Trees were treated with commonly used preservatives,

[5] This may not be necessary where grafting wax is used.

CHEMICAL SOLUTIONS USED IN TECHNIQUE DESCRIBED IN TREATING SHORTLEAF PINES INFESTED BY THE SOUTHERN PINE BEETLE AT ASHEVILLE, NORTH CAROLINA, 1929

Number of trees	Materials used in treatment*	Results of treatment: Number of trees in which the brood mortality was 100 per cent. and in which there was no blue stain (adults and eggs the only beetle stages present)	Number of trees in which the brood mortality was only partial and in which there was blue stain (larval and more advanced beetle stages present)
17	Wood alcohol	10	7
11	Carbon disulphid and kerosene, equal parts	4	7
5	Copper sulphate and water, 50 grams	2	3
1	Ethylmonochloroacetate	1	0
7	Ethylene dichloride	3	4
4	Formaldehyde and water, 1 pt. 40 per cent.	2	2
25	Hydrocyanic acid and water, 5 per cent.	16	9
2	Mercuric chloride and water, 15 grams	2	0
32	Potassium cyanide and water, 30 to 50 grams	15	17
8	Sodium arsenite and water, 30 grams	4	4
7	Sodium fluoride and water, 30 grams	4	3
Total 119		63	56

* Average dosage, 2 quarts of solution for pine trees $5\frac{1}{2}$ inches in diameter breast height and 30 feet high. The diameters of the trees ranged from 4 to 18 inches and the height from 20 to 60 feet.

such as zinc chloride, copper sulphate, sodium fluoride and arsenicals, and the logs from these trees were set in the ground with untreated checks. Ordinarily in wood-impregnation processes only the sapwood is treated, to the depth of one inch or so. This method brings about the same results by use of forces within the living tree.

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SPECIAL ARTICLES

A GENERAL THEORY FOR CALCULATING SURFACE TENSION FROM THE SHAPES OF STABLE LIQUID SURFACES OF REVOLUTION

THE general significance of Laplace's theory of liquid surfaces in the interpretation of all those methods for the determination of surface tension involving stable surfaces of revolution has not been commonly appreciated. The usual application of this theory has been through the integration of its differential equation by the use of particular assumptions. But these assumptions limit the generality of the underlying theory. In a few special cases, it is true, the theory has been applied without limiting assumptions, but even in these cases no hint has been given that the particular applications had general significance. Some methods are associated with this theory only empirically. It is the purpose of this note to state that all surface tension methods involving the use of stable liquid surfaces of revolution may be based upon the Laplace theory alone and that all of them thus are absolute methods in the sense that the value of the surface tension may be obtained from them without the use of limiting assumptions or the necessity for empirical comparison with another method.

The essence of this general method for calculating the value of the surface tension of a liquid is as follows. Draw, from the Laplace equation, the family of curves giving the shape of the surface assumed by the liquid in any of the experimental methods of this group; perform on this family of curves an operation analogous to the experimental procedure of any one of these methods, which gives a pair of corresponding quantities; construct from a number of such operations a curve one of whose coordinates is a dimensionless function of these quantities, while the other is a function the equivalent of which, for any particular liquid, involves its surface tension; and finally use this curve in connection with a measurement on the liquid whose surface tension is sought.

The shapes, though not the sizes, of liquid surfaces of revolution may be found by numerical integration of the equation expressing the Laplace theory:

$$\frac{du}{dx} + \frac{u}{x} = 2(h \pm y)$$

where the terms on the left may be considered as dimensionless ratios obtained by dividing the square root of the capillary constant of the liquid by the radii of curvature of the surface at any point, while that on the right is a ratio obtained by dividing by the square root of the capillary constant the height of a column of the liquid that would exert the pressure which exists at that point. To make this equation apply to any liquid, x, y, and h must each be multiplied by the square root of the capillary constant of that liquid, a. Numerical integration of this equation gives the various families of curves representing these surfaces, which fall into three groups which we have designated by the names meniscus, disk and drop profiles. From these families of profiles it is possible to derive a general theory for all the methods for the determination of surface tension which involve such surfaces.

An outline of our procedure by which relationships between the dimensionless quantities of the equation are used to calculate the value of the surface tension of a particular liquid will be given and illustrated by application to the capillary rise method. The first step is the preparation, from the equation, of a family of meniscus profiles, since this is the shape of the surface in a capillary tube. For the details of this step, which is rather involved especially when the data in the literature are not adequate, reference should be made to the papers mentioned below. In the second step the family of profiles is made to give the values of two dimensionless quantities, the analogues of which are measured in the experiment. In the capillary rise method these quantities are the radius of the tube and the height of the liquid in the tube between the undisturbed level of the liquid and the bottom of the meniscus. The analogous procedure is the selection of a particular value of x, which is equivalent to choosing a definite capillary and a definite liquid; the finding of that member of the meniscus family of curves which is tangent to the constant x line selected, the reading off of the value of the ordinate, y_0, of the point where this meniscus curve crosses the y-axis; and of the repetition of this procedure for other selected values of x. In the third step, from these pairs of corresponding values of x and y_0, a curve is constructed having for one coordinate a function of these quantities, whose identical function in the case of the analogous experimentally measured quantities is dimensionless, and for the other coordinate a function of x and y_0 whose equivalent function in the case of the analogous real quan-