March 6, 1945. H. C. GILLESPIE 2,370,624

ELECTRICAL HEATING METHOD

Filed Oct. 1, 1942

FIG. 1.

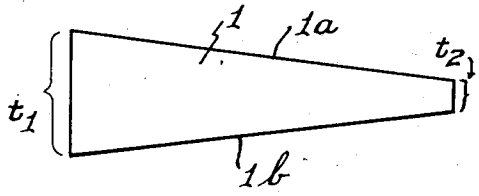


FIG. 2.

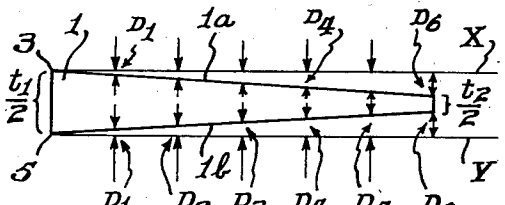


FIG. 3.

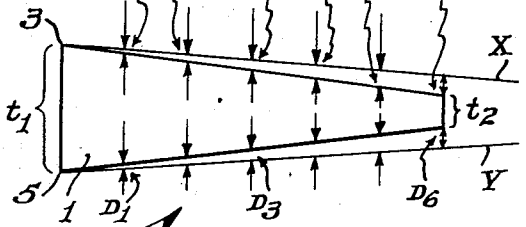


FIG. 4.

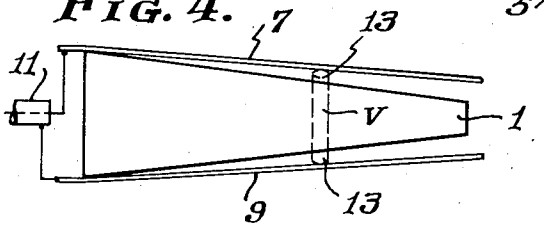


FIG. 5.

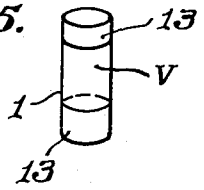


FIG. 6.

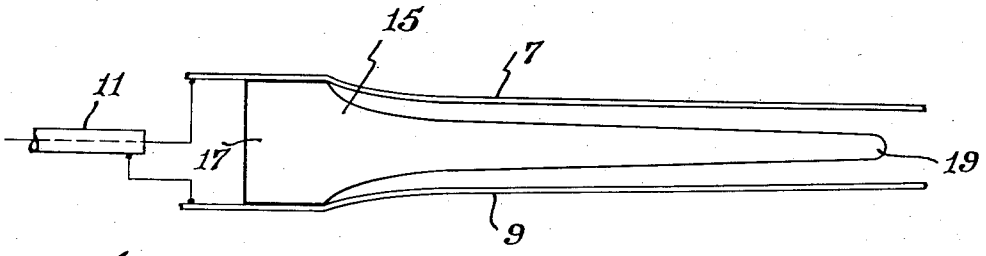
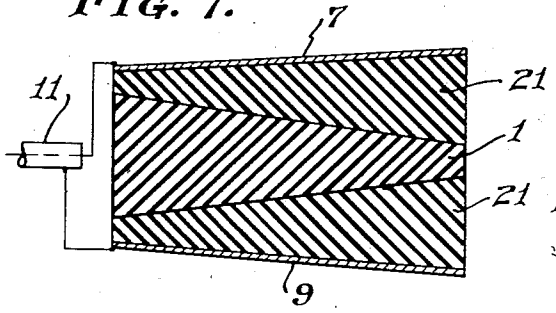


FIG. 7.



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UNITED STATES PATENT OFFICE

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ELECTRICAL HEATING METHOD

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Application October 1, 1942, Serial No. 460,338

1 Claim. (Cl. 219—47)

This invention relates to an electrical heating method, and more particularly to a method of heating dielectric materials by subjecting them to the influence of a high frequency electric field.

In conventional heating apparatus of this type, the dielectric material to be heated is placed between a pair of cooperative electrodes which engage the work throughout its length, and a high frequency voltage is applied to the electrodes. This arrangement provides a capacitor with the work as the dielectric, and the electric field set up between the electrodes causes the work to heat up. In many cases, the work is not of uniform cross section throughout its length, and if the electrodes are in engagement with the work at all positions thereof, non-uniform heating results, the thinner portions of the work becoming hotter than the thicker portions. This condition is highly detrimental in many applications and must be avoided if satisfactory results are to be obtained.

The primary object of my present invention is to provide an improved method of heating dielectric materials with the aid of a high frequency electric field, which method will not be subject to the aforementioned disadvantage.

More particularly, it is an object of my present invention to provide an improved heating method as aforesaid by means of which uniform heating of a work-piece of non-uniform cross section will be obtained.

Otherwise stated, it is an object of my present invention to provide an improved heating method which will produce uniform generation of heat in a dielectric material of non-uniform cross section.

It is also an object of this invention to provide an improved method as aforesaid which is highly efficient in practice.

In practicing this invention, the electrodes are shaped and so disposed relative to the work as to produce uniform current flow in all parts thereof. To determine the proper shape and position of the electrodes relative to the work, the dimensions of the latter are redrawn to a new thickness scale determined by dividing all thickness dimensions thereof by the relative dielectric constants of the material of the work-piece and the material of the surrounding dielectric (usually air). Electrodes then spaced from the original work-piece according to the difference in distance between two parallel lines drawn through the thickest part of the redrawn work-piece and said redrawn piece will cause high frequency current to flow uniformly through the work-piece at all portions thereof and thus heat the work-piece uniformly throughout.

The novel features that I consider characteristic of my invention are set forth with particularity in the appended claim. The invention itself, however, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description, when read in connection with the accompanying drawing wherein

Figure 1 is a side elevation of a wedge-like work-piece to be heated, this form of work-piece being taken for the sake of illustration only,

Figure 2 is a similar view of the work-piece with its transverse dimensions redrawn according to the present invention and illustrating the manner in which the position of the electrodes relative to the work is determined.

Figure 3 is a view similar to Figure 1 but with the spacing of the electrodes relative to the work indicated thereon as derived from Figure 2,

Figure 4 is a view similar to Figure 3 but showing the electrodes in proper relation to the work, as derived from Figure 3, to insure uniform heating thereof,

Figure 5 is a view representing an elemental volume of work-piece and surrounding dielectric between the two electrodes at any random point through the cross section of the work, this view being referred to hereinafter in explaining the theory involved in my invention,

Figure 6 is a view similar to Figure 4 but showing the electrodes applied to a non-uniform dielectric work-piece of other than wedge shape, and

Figure 7 is a central sectional view of a modification of the invention.

Referring more particularly to the drawing, wherein similar reference characters designate corresponding parts throughout, there is shown a wedge-shaped work-piece 1 of dielectric material, the piece 1 having a thickness t_1 at one end, where its cross sectional dimension is greatest, and tapering down gradually to a thickness t_2 at its other end, where it is thinnest. If a pair of strip or plate electrodes were applied to its converging surfaces 1*a* and 1*b*, in accordance with conventional practice, and a high frequency voltage were applied to the electrodes, the work-piece 1 would become hotter in the region of its thinnest end than in the region of its thickest end. It is this condition which the present invention obviates in the following manner:

As the first step in practicing this invention,

the work-piece 1 is redrawn or otherwise suitably reproduced in the manner shown in Figure 2 with its length the same as the original and all its cross-sectional or thickness dimensions that fraction of the original thickness as is the ratio of the dielectric constant of the medium which surrounds the work-piece 1 to the dielectric constant of the material of the work-piece. Since the surrounding medium is usually air, the dielectric constant of which is unity, if it is assumed that the dielectric constant of the work-piece material is 2, then the aforementioned fraction becomes ½. In other words, for the assumed case, the work-piece is redrawn to a thickness of one-half the original thickness, so that the thickest end of the redrawn piece is

$$\frac{t_1}{2}$$

and the thinnest end thereof is

$$\frac{t_2}{2}$$

The next step is to draw two parallel lines X and Y which contact the work-piece 1 only at the thickest portion or portions thereof, as the case may be. The lines X and Y are shown in engagement with the upper and lower edges 3 and 5 of the work-piece 1 (Fig. 2) in accordance with this step, and they may or may not be parallel to the axis of the work-piece, so long as they are parallel to each other. In Figure 2, they are shown parallel to the work-piece axis by way of illustration only, but this is not to be construed as being a necessary or required limitation. In any case, the lines X and Y are arranged parallel to each other in order to provide therebetween an infinite number of elemental volumes of work-piece and adjacent air portions any one of which volumes may be chosen at random and will be equal to any other such volume of work-piece and adjacent air portions. These elemental volumes are referred to in greater detail hereinafter in explaining the principle involved in the present invention.

After the lines X and Y have been drawn as above described, the distances D1, D2, D3 . . . D6 are read off between each of the lines X and Y and the adjacent surfaces 1*a* and 1*b*, respectively, at a plurality of spaced points along the length of the redrawn piece. These distances are then laid off from the surfaces 1*a* and 1*b* at corresponding points along the length of the piece 1 drawn to original dimensions, as shown in Figure 3. The points so laid off define the paths along which the electrodes should lie, and a pair of electrodes 7 and 9 so disposed and adapted to be connected to a source of high frequency power, such as a radio frequency oscillation generator (not shown), by a concentric line 11 is shown in Figure 4. This arrangement of electrodes relative to the work will insure uniform heating of the work at all points thereof.

For an understanding of the principle involved in the above arrangement, reference will now be made to an elemental volume V (Figs. 4 and 5) of the work-piece 1 and adjacent air elements 13 taken at random through the work-piece between the electrodes 7 and 9. Let it be assumed that the cross sectional area of the elemental volume V is dA, that the net capacity of the two air elements or particles 13 is dC_A, and that the capacity of the elemental work-piece 1 in the volume V is dC_w. The resultant series capacity dC of the elemental volume V is given by the equation

$$\frac{1}{dC}=\frac{1}{dC_w}+\frac{1}{dC_A} \tag{1}$$

If the capacity dC is everywhere the same for each elemental volume V, it is obvious that the same current will flow through each elemental volume, and therefore uniform heating of the work-piece will result. Now if

K_w=the dielectric constant of the work-piece 1,
K_a=the dielectric constant of air (unity)
t_w=the thickness of the work-piece,
t_a=the thickness of the air, and
a=a proportionality factor,

then

$$dC_w=\frac{K_w dA}{at_w} \tag{2}$$

and

$$dC_A=\frac{K_a dA}{at_a}=\frac{dA}{at_a} \tag{3}$$

Substituting Equations 2 and 3 in Equation 1,

$$\frac{1}{dC}=\frac{at_w}{K_w dA}+\frac{at_a}{dA} \tag{4}$$

or

$$\frac{1}{dC}=\frac{a}{dA}\left(\frac{t_w}{K_w}+\frac{t_a}{1}\right) \tag{5}$$

Now, if, at every point in the work, we make

$$t_a=\frac{T-t_w}{K_w}=\frac{T}{K_w}-\frac{t_w}{K_w} \tag{6}$$

where T is the maximum thickness of the work, then, substituting Equation 6 in Equation 5,

$$\frac{1}{dC}=\frac{a}{dA}\left(\frac{t_w}{K_w}+\frac{T}{K_w}-\frac{t_w}{K_w}\right) \tag{7}$$

or

$$\frac{1}{dC}=\frac{aT}{dAK_w} \tag{8}$$

whence

$$dC=\frac{dAK_w}{aT} \tag{9}$$

In other words, the capacity of each elemental volume V is the same as at the thickest part of the work where the electrodes are in contact with it, which means that each elemental volume offers the same impedance to the flow of current therethrough as does the thickest part of the work. Consequently, the current will be uniform at all parts of the work-piece 1 and the piece will be uniformly heated throughout.

Figure 6 illustrates an instance in which practical application may be made of this invention. In this figure, there is shown a propeller blade 15 which may be made of wood laminations bonded together by an adhesive cement adapted to be activated by a radio frequency electric field. The blade 15 has a thick portion 17 extending a substantial distance from its base and beyond the base portion it gradually thins down as it approaches its tip 19. Were the electrodes 7 and 9 "form fitted" to the blade 15, so to speak, it is obvious that the portion thereof in the region of its tip 19 would heat much more rapidly than the base portion and might even char before the base portion 17 would be heated sufficiently. However, by placing the electrodes 7 and 9 in engagement with the thick, base portion 17 only and from there on spacing the electrodes from the blade in the manner heretofore

described, uniform heating at all parts of the blade will be insured.

In the modifications thus far described, the work-piece 1 is assumed to be immersed in air, and, with the electrodes spaced therefrom as above described, no pressure can be applied to the work, as is sometimes necessary during the heating operation. To meet this situation, the work-piece 1 may be placed between or surrounded by a second, low-loss, dielectric material 21 and the electrodes 7 and 9 placed against the material 21, as shown in Figure 7. The material 21 may be porcelain, for example, or any one or more of a number of other suitable materials which can withstand the required pressure, such as those known commercially as "Isolantite" and "Mycalex." In any event, the thickness dimensions of the material 21 should be determined similarly to the air thickness represented by the distances D1, D2 . . . D6 in Figures 2 and 3. If found desirable, the material 21 may space the electrodes 7 and 9 from all points of the work-piece 1 along its entire length, as shown in Figure 7, but if it is suitable to place the electrodes in direct engagement with the work, then this should be done only at the thickest portions thereof and the material 21 used to fill in the spaces left between the electrodes and the work at all other points.

Although I have shown and described several forms of my invention and several ways in which it can be carried into practice, it will be obvious to those skilled in the art that many others are also possible. I therefore desire that my invention shall not be limited except insofar as is made necessary by the prior art and by the spirit of the appended claim.

I claim as my invention:

In electrical heating apparatus for heating a dielectric work-piece of non-uniform cross section throughout its length and embraced by a second dielectric material having a different dielectric constant than the material of said work-piece by subjecting said work-piece to a high frequency electric field between a pair of cooperating electrodes, the method of positioning said electrodes relative to said work-piece which comprises first reproducing said work-piece to the same length dimension as said original work-piece but to that fractional cross-sectional dimension thereof which is the ratio of the dielectric constant of said second dielectric material to the dielectric constant of said work-piece material, then disposing two parallel lines which pass through only the thickest portions of said reproduced piece, then measuring off at a plurality of spaced points longitudinally of said reproduced piece the transverse distances between said reproduced piece and said parallel lines, then laying off said transverse distances in a transverse direction from said original work-piece at correspondingly spaced longitudinal points thereon, the terminals of said last named transverse distances defining the paths of said electrodes, and finally disposing said electrodes along said paths.

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