TABLE 2 TEST FIGURES FOR POLYVINYL-CHLORIDE FILM

	Tensile			Elmendorf tear			Elongation, per cent		
	Kilograms			grams					
	A	B	d, per cent	A	B	d, per cent	A	B	d
Nonvented.......	3.5	3.3	24	432	864	19	447	600	16
Electrovented....	2.8	2.6	19	272	928	23	313	427	25

crease in strength over a wide range of electrovent porosities. However, at a critical value of porosity, the strength values begin to drop off sharply. Curves of tear and tensile strength, both in the machine and cross-machine directions, for Alabama Kraft sheets are shown in Fig. 10. The paper has an initial porosity of 16.7 secs for 300 cc of air. Samples were then electrovented to give porosities of approximately 10, 4, 3, and 2 sec, respectively. The decline in the tear and tensile properties is negligible until a value of from 4 to 5 sec is reached; decline is then rapid when the porosity is increased from this critical range. Whether or not similar relationships exist for plastic sheets has not as yet been determined. However, the test figures[3] for two samples of polyvinyl-chloride film (of 5 mil gage) are recorded in Table 2. The tensile and elongation tests were made on strips 1.5 cm wide. A and B are directions which are at right angles to each other and are in reference to the forces applied in testing; d is the maximum deviation of a single reading from the average, the latter being the result of 5 tests.

CONCLUSIONS

Electroventing permits a control of porosity in sheet materials which has hitherto been unobtainable. Application of the process has already been made to the venting of paper, hats, and shoes; its possibilities in the field of plastic sheet materials are numerous. A porosity-control process in the manufacture of paper permits the paper manufacturer to concentrate on the strength of the sheet without regard to porosity considerations; thus one of the variables in the manufacturing stages is removed. When cellulose or plastic films are applied to the packaging of food, a need for porosity may arise.[4] Electroventing provides a means of adding any desired porosity to the film to meet various types of packaging requirements. In the application of plastic materials to apparel use, occasions arise where porosity becomes a critical consideration. By electroventing, pores of a permanent nature may be processed into the plastic film and thus provide it with the "breathing" quality so often desired in apparel materials. When fully developed in the numerous fields where it may apply, electroventing undoubtedly will open up large new areas for the use of plastic sheet materials.

Discussion

H. W. MOHRMAN.[5] The principle of electroventing is an interesting technique that promises to widen the applications of plastics in fields where more porous materials such as leather have been used. The author is to be complimented for his treatment of air flow through porous plastics and control of this porosity by electroventing.

In the paper a mathematical theory of the electroventing process has been derived. However, not enough experimental data are given to really test the equations. The validity of some of the assumptions made in the derivations may be open to question. Unless these assumptions can be justified by further experimental data, the final equations may only indicate trends of a qualitative nature.

The assumption is made that the voltage required to bring about a dielectric breakdown is proportional to the thickness of the material. However, both theory and experimental data show that, in most cases, the breakdown voltage increases as the square root of the material thickness rather than directly as the thickness. It is also improbable that the resistance R is independent of both time and current as has been assumed in deriving Equation [12].

H. E. LUSTIG.[6] This paper is apparently the first one dealing with an analysis of the "electroventing" process. In view of the increasing applications of that process, it should be welcomed by industry.

In the second section of his paper, "Electric Control of Porosity," the author may be guilty of oversimplification of discharge phenomena. The nature of these is not yet completely understood and their analysis, because of the nonlinear relations involved, is consequently subject to empirical procedures. In so far as basic engineering applications are concerned, however, the author has achieved his purpose.

The following symbols are defined as:

E = source voltage
E_g = gap voltage
E_b = breakdown voltage of dielectric
E_e = extinction voltage of air

It is obvious for the direct-voltage case that prior to the striking of the arc $E = E_g$, and that at the instant of breakdown, $E = E_g = E_b$. If we now assume, as the author does, that the internal circuit resistance is r, and that the arc itself may be represented by an equivalent resistance R, then it follows that after firing, source voltage and gap voltage are no longer the same, but rather

$$E_g = ER/(R + r)$$

In view of these fundamental considerations, Equation [9] of the paper is correct for the general case, but the statement preceding it applies to a very special case only. In order for the arc to "be maintained until the extinction voltage of the arc becomes equal to or greater than the breakdown voltage of the material," resistance r must be zero or negligible with respect to R. This does not conform with practice since, generally, r is much greater than R.

The confusion of voltage definitions appears again in Equations [16] and [17]. Extinction occurs abruptly when a certain value of minimum current through the arc is reached. As a result, the gap voltage at extinction is still considerably less than the source voltage and the E in Equation [16] should actually be E_g. The author then returns to Equation [14] and substitutes (E/r) for current I, which is correct for the assumption that $r \gg R$. As soon as Equation [16] is substituted, however, it should be in terms of the same voltage E, which is source voltage. Thus, applying the correction factor between E and E_g, as just given, Equation [17] becomes

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[3] Report No. 330272, Electrical Testing Laboratories, Inc., New York, N. Y., February, 1949.

[4] "Comparison of Film Types and Film Perforations in Tomato Prepackaging," by J. Kaufman and H. W. Hruschka, *Pre-Pack-Age*, New York, N. Y., vol. 3, February, 1950, pp. 16–18.

[5] Director of Research, Monsanto Chemical Company, Plastics Division, Springfield, Mass.

[6] Ford Instrument Company, Long Island City, N. Y.; formerly Electrical Engineering Department, The Copper Union, New York, N. Y.

$$W = \frac{\mu E^2 Rh}{(r + R)^2 v}\left(\frac{2KmER}{(2170)^2 (r + R)} - 1\right) \approx \frac{\mu Rh}{r^2 v}\left(\frac{2KmE^3R}{(2170)^2 r} - E^2\right) \qquad [21]$$

It may be seen that this relation does not lend itself to a simple normalization as shown in Fig. 7 of the paper. Even with the assumption that $r \gg R$, a factor of R/r remains associated with the cubic voltage term and may influence the result greatly.

In a detailed analysis of the process, some other factors would have to be taken into consideration. One of these would be a rigorous treatment of the resistance R itself, without the simplifying assumption that it is not a function of current or time. Another of these would be allowance for the series air gap which may exist between the movable electrode and the dielectric sheet. Assuming an air gap of length a, a dielectric thickness d, and a dielectric constant ϵ_d, the effective dielectric constant of the two media may be shown to be given by

$$\epsilon = \frac{(d + a)\epsilon_d}{(d + a\epsilon_d)}$$

Furthermore, the power factor of the two media in terms of the dielectric power factor PF_d, becomes

$$PF = \frac{d\, PF_d}{(d + a\epsilon_d)}$$

The foregoing analysis may serve only as a guide, however, since it assumes a parallel electrode arrangement which is only a first approximation to analysis of point-discharge phenomena. The inclusion of additional air gap and of power factor would have unnecessarily complicated the analysis, but in a search for optimum economic operation of the "electroventing" process, such factors may have to be considered.

It may be noted in passing that Equation [10] of the paper lends itself to a novel method of dielectric-constant determination for the particular dielectric being processed. With suitable recording devices and with the particular breakdown potential of air known for the test conditions, the dielectric constant may be determined with fair accuracy by a method considerably more economical than the susceptance variation, Q-meter, and direct deflection methods commonly employed for the purpose.

G. B. Thayer.[7] The data presented in this paper are of much interest to engineers engaged in manufacturing plastic films and in packaging various materials in plastic films.

These engineers would find it interesting to have additional data on more different types of plastic materials. Quite possibly such data will be forthcoming as work continues with the machinery for electroventing.

One question which is of extreme interest to the plastic sheet manufacturer is "What effect does sheet-thickness variation have upon the control of porosity achieved by the principles described in this paper?"

Mr. Suran found little or no decrease in physical properties of paper and polyvinyl chloride sheets when tensile tests were made. It would be interesting to know what the effect of electroventing is upon plastic sheets which have low-tear strength and low-percentage elongation.

Mr. Suran has not stated what effect electroventing will have on water-vapor transmission figures. This is an important consideration when the film is to be used for packaging certain foods as stated in the concluding paragraph. We think it would be useful if such data were available to publish it subsequently.

It is suggested that the formation of oval-shaped holes in some plastic films could come about from different amounts of orientation at right angles to the direction of formation of the film. Polyethylene film probably is oriented into two directions, and it may have been this film that the author reported as having oval-shaped holes. Polyvinyl-chloride-calendered film is likely to be produced without appreciable orientation in either direction, and it would be expected to perforate with round holes.

AUTHOR'S CLOSURE

The author is indebted to the discussers for expanding upon and re-emphasizing the simplifying assumptions made in the development of the theory pertaining to air flow through porous sheet materials and to the electric control of porosity. Messrs. Mohrman and Lustig are justified in objecting to the assumption of a constant R in the development of Equation [11]. By making this assumption, however, the solution of a nonlinear differential equation of considerable complexity is avoided, and the resultant error due to the approximation of a linear R is generally found to be within the limits of the experimental statistical deviations.

Mr. Mohrman's observation concerning the nonlinear variation of dielectric breakdown strength with the thickness of the material is quite correct if the thickness is considered to vary between zero and infinity. Since electroventing is economically limited to sheet materials having thicknesses between approximately 0 and 50 mils, the breakdown voltage characteristics need be considered over only this limited range. As the experimental curve of Fig. 6 illustrates, many plastics may thus be characterized by a linear function.

Mr. Lustig's correction of Equation [17] is appreciated. The curves of Fig. 7 should be modified accordingly.

Mr. Thayer has raised several interesting questions, some of which cannot be answered conclusively at this time. Sheet-thickness variation is known to cause similar variation in the control of individual hole size and differential hole density, but by means of servomechanical controls the *average* porosity may be maintained constant within any desired tolerance limits. The effect of electroventing plastic sheets which have low tear strength and low-percentage elongation properties has not been investigated. Electroventing paper with such initial low-strength properties generally reduces the strength characteristics (on the basis of per cent strength reduction per second porosity increase) faster than would be the case for papers with initial high-strength properties.

From preliminary experimental results, there does not seem to be a correspondence between increased air-flow porosity and increased water-vapor transmission rates due to electroventing. The indication is that increased water-vapor transmission is much less than increased air transmission. Theoretical considerations would lead us to expect this since the thermodynamic properties of a vapor are considerably different from those of a gas. Hence Equation [3] is not applicable to water vapor.

The oval shape of electrovented holes in plastic materials is due essentially to the flow motion introduced by the relative movement between electrode and material, although differences in molecular orientation also affect the perforation shape. All of the plastic materials which have been electrovented thus far are found to contain holes of an elliptical nature with the major axis of the ellipse oriented in the direction of sheet motion.

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[7] The Dow Chemical Company, Midland, Mich.