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Characterization of Organic Illumination Systems

Bill Hamburgen
Jeff Mogul
Brian Reid
Alan Eustace
Richard Swan
Mary Jo Doherty
Joel Bartlett

digital **Western Research Laboratory** 100 Hamilton Avenue Palo Alto, California 94301 USA

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Abstract

Recent anecdotal reports of novel principles of illumination have stressed qualitative aspects. This note presents a quantitative study of an organic illumintation system, characterizing the temperature and current-flow properties of the system as functions of time and device parameters. Theoretical and practical implications of these measurements are discussed.

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1. Introduction

There has been a great deal of interest of late in triboluminescence and electroluminescence in organic materials. Triboluminescence in wintergreen Life Savers® has been investigated by many over the years [8], while electroluminescence in organic thin films is an active area of current research both here and abroad [10].

In early December 1988, our attention was called to work by Bill Bidermann on electroluminescence in pickles [23]. It was reported that inserting iron electrodes into a dill pickle and energizing with modest alternating currents caused the pickle to glow. Subsequent reports reached us in January 1989 regarding corroborating experiments [15, 21]. We decided to investigate the phenomenon with the aim of improving our understanding of the underlying mechanisms and examining the potential for commercial applications.

2. History of Incandescent Illumination Devices

Our experiments indicate that pickles are a form of incandescent lamp. In this light, it is useful to consider the historical development of such devices.

Sir Humphrey Davy first demonstrated in 1802 [3] that platinum strips heated in the open air with electricity emit light. Frederick de Moleyns was granted a patent for an incandescent bulb in 1841 [3]. He used charcoal between platinum wires. Sir Joseph Wilson Swan (no relation to one of the authors) produced the first lamp with carbon filaments in evacuated glass bulbs [3]. This exciting invention was brazenly copied a year later by a minor American inventor and industrialist [3].

3. Theory of Organic Illumination Devices

While the exact mechanisms are unclear, our observations lead us to propose the following model of light generation. Upon initial application of power, the pickle conducts strongly. This is not surprising since the pickle is thoroughly impregnated with a highly ionic sodium chloride salt solution. Resistive losses cause the pickle to heat. One would expect the heating to be the greatest in the vicinity of the electrodes where the current flux is highest.

When the temperature at the surface of the electrode reaches about 100 degrees C, boiling occurs. The water vapor generated locally blankets the electrode. This vapor is non-ionic and not conductive, and if sufficiently thick, current can no longer flow from that point on the electrode surface. Of course as soon as the local current flux ceases, the heating at that point ceases as well, at the area begins to cool. When the area has cooled sufficiently, the vapor blanket collapses and conduction and heating resume. At some point during the transition to or from the conducting condition, an arc is supported and light is produced. It appears that a quasi-equilibrium state is reached providing a relatively steady light source. The composition of the plasma in the arc is not known but may contain hydrogen (from decomposition of water and the sample's organic constituents), carbon (from the sample), and various atmospheric gases. A spectroscopic observation of the arc, perhaps through a fiber optic probe, would help elucidate the composition.

4. Experimental Media

We performed experiments on five different experimental media. As previous work had focussed exclusively on pickles, we acquired three different varieties of pickles. Because we were attempting to characterize the properties of the various media, we purchased high-quality samples from Draeger's market, at somewhat higher than prevailing costs. Commercial exploitation of this phenomenon would of course require bulk purchases to obtain reduced prices, with the attendant quality control issues.

Two of the pickle varieties, the ‘‘Kosher’’ and the ‘‘Dill’’, were substantial specimens, measuring approximately 1.5" diameter. The ‘‘Kosher’’ pickle was 5" long, while the ‘‘Dill’’ pickle was 5.5" long. The third variety of pickle, chosen for experimentation with miniaturization of this technology, was a ‘‘Cornichon’’ pickle, measuring about .5" in diameter and 1.5" long. The two larger pickles were slightly below ambient temperature at the start of the experiment; the smaller pickle had reached thermal equilibrium. All pickles used were whole and undamaged.

Standard preparations for some of these media are presented in Appendix I; we do not know if the pickles we used in fact followed the standard preparations.

We also tried to elicit electroluminescence in two non-pickle media, a segment of ‘‘Mandarin Orange’’ (raw) and a piece of stir-fried ‘‘Bok Choy.’’ Although a pickle is technically a ‘‘fruit’’[1] it is not commonly thought of as such; an orange is indisputably a fruit. Also, although both pickles and oranges are acid media, they differ in that pickles are ionic (‘‘salty’’) whereas oranges are non-ionic (‘‘sweet’’). Bok Choy, on the other hand, is clearly not a fruit, and is only slightly ionic; in fact, it has rather less taste than the other media. Our Mandarin Orange sample was about 1" long; the Bok Choy sample was about 2" long, .75" wide, and not very thick.

5. Experimental Method and Setup

Our apparatus consisted of a fused AC line cord, the ends terminated with bare .1631"/.1571" diameter CDA10100 copper electrodes. To facilitate insertion, the ends of the electrodes were ground to a conical shape with a 60 degree included angle. The line cord was powered through a YEW Model 2509 Digital Wattmeter, which was used to monitor the current during the experiment. To protect the wattmeter, a 10 Amp instrument fuse was used; this proved adequate for the five trials described herein, though it did blow later during some informal testing. Small currents were noted prior to energizing some of the test samples. The source of these currents was not determined, but as the magnitude was typically small compared to that measured while energized, it is not felt that this was an important source of error. The two electrodes were placed in the test sample in either an axial or parallel configuration, depending on the shape of the test sample. The electrode orientation, penetration, and separation were recorded in each instance. The voltage was checked at the beginning of the series of experiments and found to be approximately 113 VAC RMS.

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[1] ‘‘**fruit**: **1** d) a product of fertilization in a plant with its modified envelopes or appendages; specifically: the ripened ovary of a seed plant and its contents.’’ [22]

Temperature in the vicinity of the electrode was sensed with a .030" diameter stainless steel sheathed grounded type K thermocouple probe. To ease penetrating the tough skin of the test sample, the thermocouple probe was bonded into a 21 gage syringe needle with the tip of the probe projecting approximately .080". The thermocouple probe was positioned with the tip in contact with the end of the #1 electrode. It was found that as the experiment progressed, heating caused deformations in the test sample that could shift both electrode and thermocouple locations. Since the temperature gradients could be expected to be large in the vicinity of the electrode, our temperature measurements should be considered as more a qualitative than a quantitative indication of conditions near the arc.

Table 1 shows the electrode orientation, separation, and penetration depths for each of the five experimental media that we used. Figure 1 shows a schematic depiction of the experimental setup (axial orientation).

Dimensions in inches				
Subject	Electrode orientation	Electrode separation	Electrode #1 penetration	Electrode #2 penetration
Bok Choy	parallel	0.5	0.5	0.5
Mandarin Orange	parallel	0.38	0.38	0.38
Cornichon	axial	0.5	0.5	0.5
Kosher Pickle	axial	2.5	1.0	1.5
Dill Pickle	axial	2.5	1.5	1.5

Table 1: Electrode positions

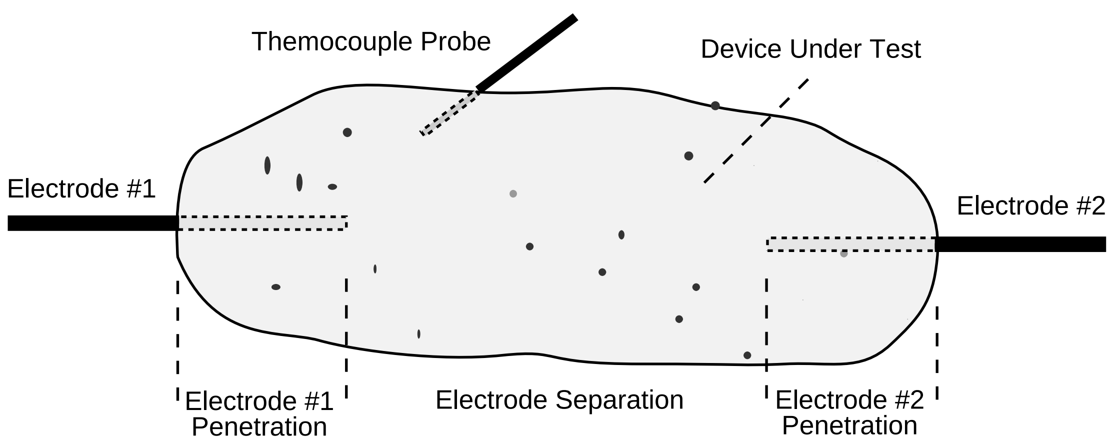

Figure 1: Schematic depiction of experimental setup

6. Measurements

In each of the five cases, the temperature and current were recorded at the start of the experiment, just prior to energizing the sample. Additional data was taken at elapsed times of 5, 10, 20, 40, and 80 seconds. Temperature and current data are presented in tables 3 and 4, respectively. We also present graphs of both temperature and current versus time, in figures 2, 3, 4, 5, and 6.

Observations were also made of the approximate time of arc initiation and quenching. These observations are summarized in table 2. An existing light photograph was taken of one of the samples while its light output was at a peak.

Subject	**Arc size**	**Arc started**	**Comments**
Bok Choy	Irregular	At about 20 sec	
Mandarin Orange	Never really lit up		
Cornichon	Small	At about 20 sec	
Kosher Pickle	Large	At about 15 sec	Arced on top side of electrode, sank as it burned. Pickle expert reports ‘‘it still tastes a lot like a pickle’’ afterwards.
Dill Pickle	Really good	At about 10 sec	Arced on top side of electrode, sank as it burned. Photograph taken. Arcing decreased at about 35 seconds, increased again at about 55 seconds.

Table 2: Qualitative observations

Temperature (Degrees C)						
Subject	0 sec	5 sec	10 sec	20 sec	40 sec	80 sec
Bok Choy	19.2	19	159	167	147	127
Mandarin Orange	21.8	25	43.4	96	99	97
Cornichon	14	110	103	101	87	72
Kosher Pickle	13	110	122	104	100	97
Dill Pickle	14	128	126	87	53	45

Table 3: Subject Temperature vs. Time

Current (Amperes)						
Subject	0 sec	5 sec	10 sec	20 sec	40 sec	80 sec
Bok Choy	.16	.63	.90	.99	.30	.16
Mandarin Orange	.4	.23	.4	.37	.29	.27
Cornichon	.13	.35	.36	.52	.13	.13
Kosher Pickle	.12	4.24	4.83	3.99	1.99	1.08
Dill Pickle	.1	5.9	5.6	.87	.37	.7

Table 4: Subject Current vs. Time

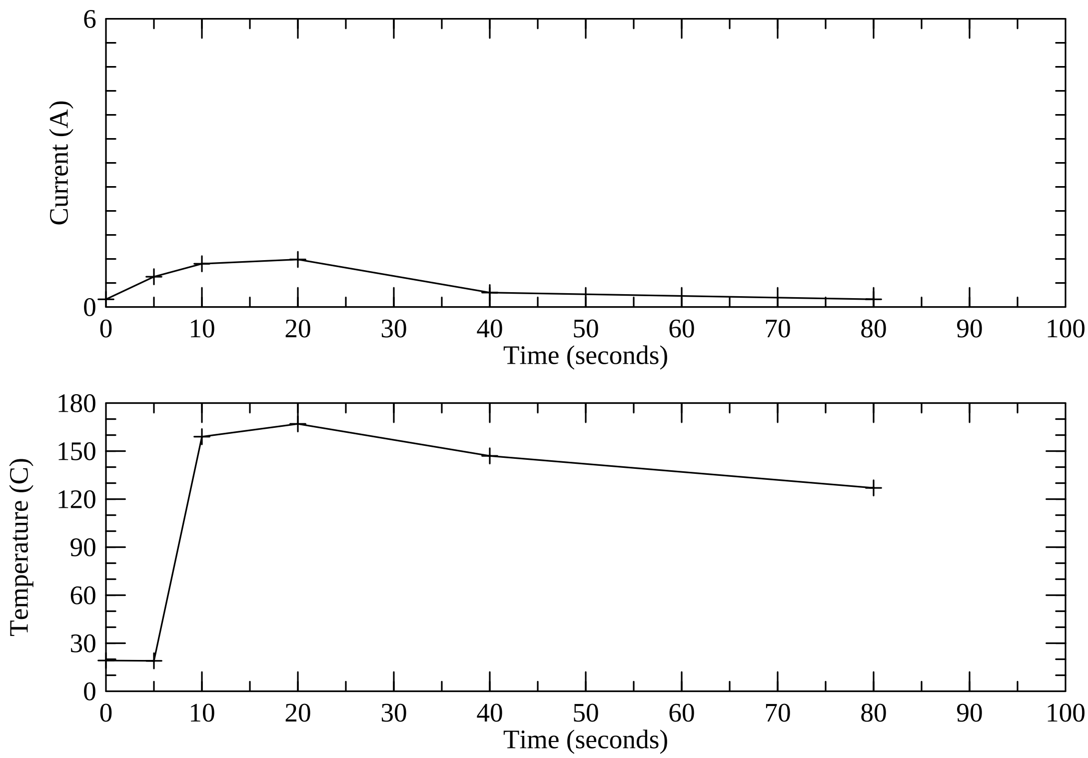

Figure 2: Bok Choy: current and temperature vs. time

7. Analysis

It appears that liquid phase ionic conduction is necessary for heating leading to arc initiation. The Mandarin Orange, which was the only sample not prepared with a brine solution, was also the only sample that did not light up.

Informal experiments beyond those reported in section 6 support the importance of the sample's ‘‘salty’’ aspect. Domestic sweet pickles (Del Monte) were found to produce a very disappointing arc in comparison with the saltier Dill and Kosher pickles. (They also tended to fall off the electrodes.)

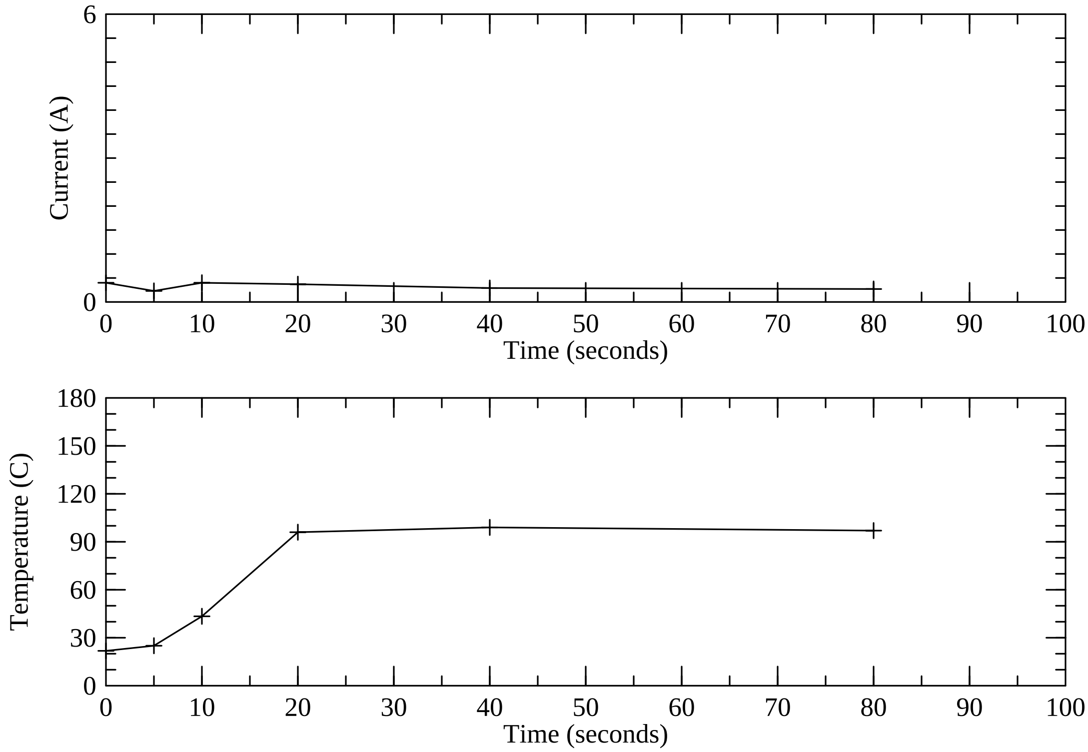

Figure 3: Mandarin Orange: current and temperature vs. time

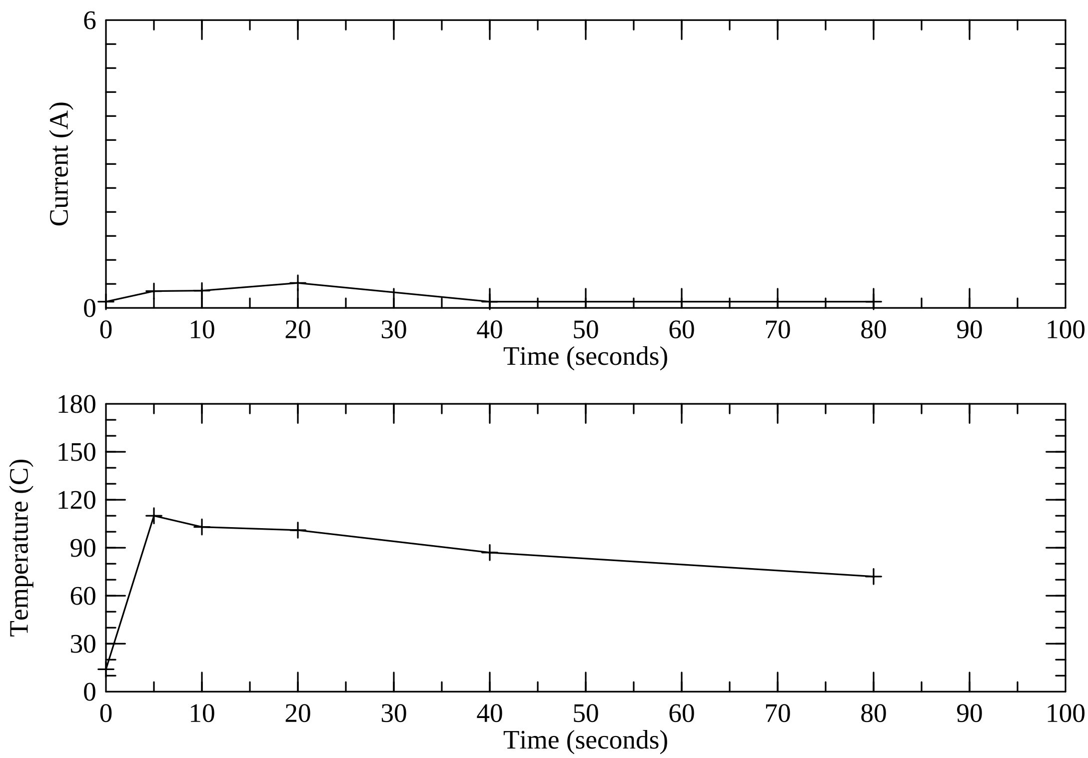

Figure 4: Cornichon pickle: current and temperature vs. time

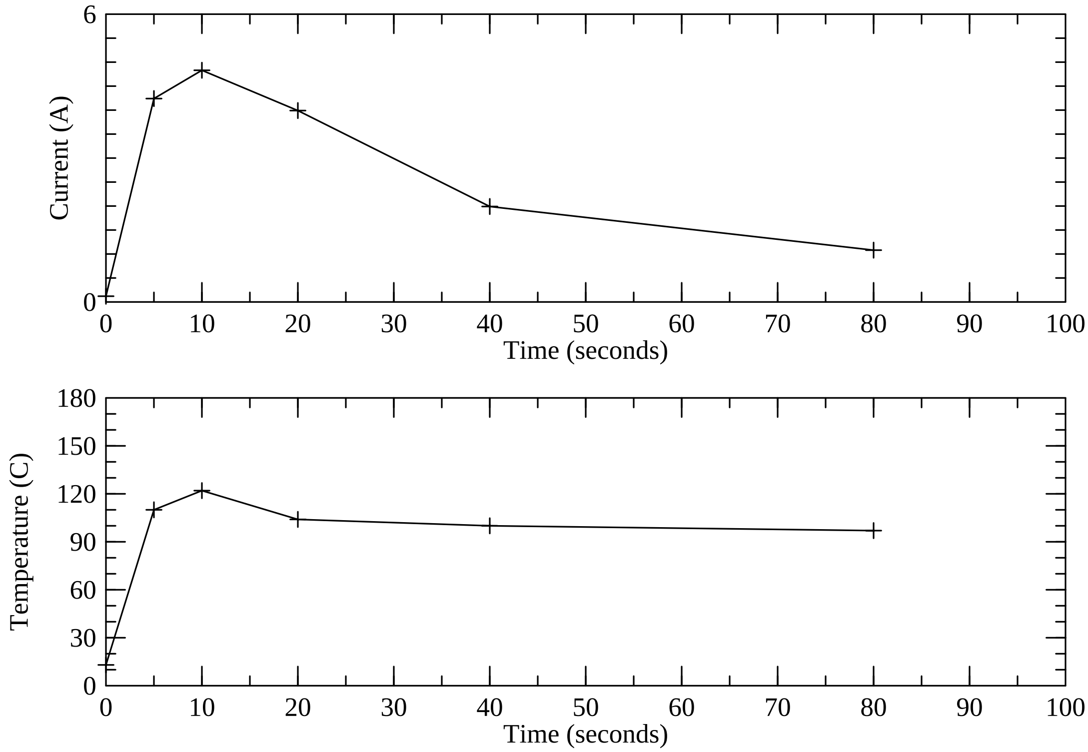

Figure 5: Kosher pickle: current and temperature vs. time

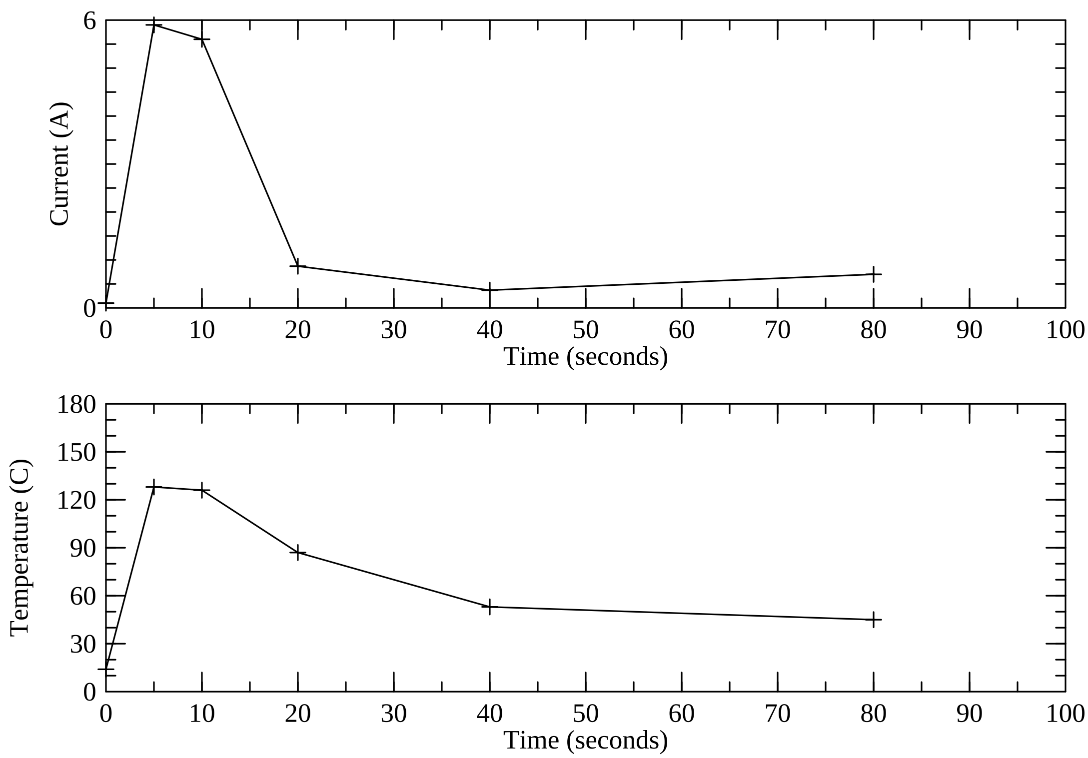

Figure 6: Dill pickle: current and temperature vs. time

In all cases arcing commenced only after vapor evolution was observed from the vicinity of the electrode surface. The initiation of the arc also corresponded closely with the measured temperature reaching the boiling point of water. In all cases with strong arcing, the current decreased markedly with the onset of arcing. This supports the hypothesis of the vapor blanketing mechanism as the initiating effect.

We also found that arcing pickles smell bad. While this is not a serious impediment to laboratory investigation, it may prove to severely limit opportunities for exploiting this technology commercially.

8. Gastronomical effects

We also investigated the effect of electrical simulation upon the gastronomical qualities of pickles. Subsequent to electrostimulation, the ‘‘Kosher’’ pickle was dissected using standard laboratory techniques to extract a .2 inch slice, roughly equidistant between the two electrodes. Careful examination revealed no tissue scarring, but a small loss of moisture content. Surprisingly, this slice did not exhibit the egregiously noisome odor noted in section 7. Further testing indicated that the taste was neither enhanced nor diminished, but remained ‘‘very much like a pickle.’’ Our conclusion is that the culinary potential of electrical stimulation is limited.

9. Practical considerations

The primary advantage of pickles as light bulbs is that they can be eaten, either before or after providing illumination. Thus they are to be preferred for long sea voyages. Pickles are also organically grown and so do not contribute to pollution. However, whereas incandescent lamps can be manufactured by a single machine at a rate of 20 or 30 per minute [4], proper pickling takes several weeks and requires careful control [5]. Thus the challenge to economically exploit the rediscovery of pickle light sources comes down to developing techniques for the massive growing of cucumbers and efficient vast vats for pickling. This may be an excellent industry for the Developing world.

10. Further Work

In the area of commercial viability, it has been noted that the very small color range of organic illumination systems is a serious drawback [10]. Certainly concentrating entirely on pickles will limit us mainly to green hues. Ripe (black) olives, which are also prepared in a brine solution, may provide an extension to the available color spectrum, and also result in a more compact fixture than pickles. Issues involving the translucence of olives and the smaller fittings required will have to be explored.

Our investigation leaves a number of unanswered questions; the most fundamental relate to the critical electrode/sample interface. Use of direct current would show whether a stable arc can be supported in cases where the voltage does not periodically drop to zero, and help determine if the arc forms preferentially at the positive or negative electrode. Spectroscopic observation could determine which plasma species contribute the light, and a photosensor and appropriate recorder could aid in elucidating arc dynamics. Novel experimental electrode designs might further promote understanding of the phenomenon by permitting better control of geometry and more direct observation of the arc. High speed photography may help answer the question concerning which phase produces the light; transition to or from the conducting state. It is hoped that other investigators will pick up the torch (with due attention to avoiding electrocution) and carry on this important work.

11. Acknowledgements

We wish to acknowlege the contributions of our laboratory assistants, Carol Peters and Bob Alverson, without whom our experiments could not have taken place.

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Appendix I. Construction of experimental media

Dill Pickles

This is the standard American pickle recipe, which has been used since the revolutionary war. The addition of garlic and chili peppers happened sometime in the 19th century, probably as a result of immigrants from southern Europe.

2 large sprigs of dill
4 pounds of small unwaxed cucumbers
3 peeled garlic cloves (optional)
1 dried chili pepper
1 teaspoon mixed pickling spice
1/8 teaspoon alum
7 cups water
1/3 cup kosher salt (uniodized)
1/2 cup cider vinegar

1. Wash and dry the dill. Scrub the cucumbers under cold running water and trim away any bad spots.
2. Place garlic, spices, and alum nearby, and place the water, salt, and vinegar in a saucepan to heat while you pack the pickles.
3. Stir the brine occasionally until salt has dissolved.
4. In a hot, sterilized, widemouth quart jar, pack the dill, a vertical layer of cucumbers and a garlic clove. Pack a second layer of cucumbers, two more garlic cloves, and the dill sprigs.
5. Add 1 teaspoon of pickling spice and the chili pepper and the alum.
6. When the jar is full, bring the brine to a boil and pour it, boiling hot, over the cucumbers to fill jars almost to overflowing. Clean rims and threads and seal.
7. Ferment the pickles for at least a month, until they are a uniform deep green color.
8. When the pickles have stopped fermenting, add extra brine to fill the air space.

Fresh-pack Kosher pickles

The fresh-pack technique for pickling uses the combination of the acidity of the vinegar and the heat of the processing bath to complete the brining process without fermenting. This recipe evolved from one originally printed in the Ellsworth (Maine) *American* in the late 1960's.

2 large sprigs of dill
4 pounds of very fresh medium cucumbers
3 cups of white vinegar
3 cups of water
1/2 cup of kosher salt (uniodized)
1 clove garlic, peeled and sliced
1 teaspoon mustard seeds

1. Wash the cucumbers.
2. Bring to a boil a brine made with the vinegar, water, and salt.
3. Cover the bottom of a 1-quart pickling jar with dill; add garlic and mustard seed.

4. Pack 1 layer of cucumbers into jar, then cover with more dill and add another layer of pickles.
5. Fill jars with boiling brine to within 1/2 inch of the top.
6. Process for 5 minutes using standard vegetable-canning techniques.
7. Cool the jar and age at 5 days. Refrigerate after opening.

Cornichons

The *cornichon* is the French sour pickle, made from tiny cucumbers about the size of your smallest finger. These plants are not grown commercially in North America, though seeds are available by mail order for gardeners who wish to grow their own. In France, the Paris small green cornichon cucumber (*le vert petit de Paris*) is harvested before it is ripe, early summer. This recipe was translated by Brian Reid from the *cornichons au vinaigre, a froid* recipe in the *Larousse Gastronomique* [6, p. 305].

2 liters spring water
30 grams salt
10 grams caster sugar
2 kilograms Paris small green cornichon cucumbers
2 fresh fennel sprigs
2 bunches blackcurrant leaves
12 peeled white pickling onions
1 bay leaf, crumbled
2 sprigs fresh thyme
2 sprigs fresh tarragon
3 cloves garlic, peeled and sliced
1 small chili pepper
6 black peppercorns
6 coriander seeds
1 liter white wine vinegar

1. Boil the water with salt and sugar, then cool completely.
2. Individually wash and dry cucumbers; place in a glass jar in layers separated by fennel and blackcurrant leaves.
3. Fill jars with salted water; marinate overnight in a cool place.
4. Drain cucumbers, rinse each in vinegared water, pat dry, and place into sterile dry canning jar.
5. Scald and dry the tarragon, thyme, and chili pepper.
6. Add peeled onions, crumbled bay leaves, scalded dried herbs, garlic, chili, peppercorns, and coriander seeds.
7. Cover cucumbers with white wine vinegar, seal jars using proper canning technique, cool, and store.
8. Age at least 6 weeks in a cool place. They will improve with age for up to 1 year.

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