AN ALTERNATE METHOD FOR MEASURING THE HEATING POTENTIAL OF MICROWAVE SUSCEPTOR FILMS

T. Labuza and J. Meister

This study evaluated the importance of measuring caloric output as a parameter for characterizing microwave susceptor performance. A simple method for performing this measurement is described. It was found to be effective at distinguishing differences in susceptor samples where other methods, such as temperature profiles, could not.

Key Words:
Microwave, Susceptor, Caloric output, Heat flux.

Microwave susceptors have become an integral component of many microwave food packaging systems over the past ten years. A microwave susceptor, as defined in this article, is a packaging component that will absorb microwave energy and convert it to sensible infrared heat energy. The use of a susceptor for browning and crisping in the microwave oven has been applied to such foods as popcorn, pizza, fish, and sandwiches. As with anything, attempts to improve the susceptor's performance are continually being made.

Changes in the general makeup of the susceptor have been explored. In the case of traditional metallized susceptor films, exploration has included the type of metal deposited [Larson, 1988] and substrate on which it is deposited [Anon, 1989]. There also have been more drastic attempts at changing the susceptor, beyond the metallized film type. These have included printed ink systems [Babbitt, 1991], and modified ceramic susceptors [Seaborne, 1988], among others. These alternate susceptor types have yet to be commercialized with a product application.

In order to understand and utilize the functional changes taking place, as well as efficiently utilizing existing commercial susceptors, methods of characterizing the performance of a susceptor are needed. Traditionally, this has been done by empirical analysis of the response of a food load, i.e., browning, or by measuring the heating response in terms of a change in the surface temperature of the susceptor. With the advent of fluoroptic measuring devices [Berek and Wickersheim, 1988], measuring surface temperatures of susceptors, as well as other components within the microwave oven, has become relatively easy.

However surface temperatures of the susceptor can be misleading, since the surface temperature is a single point measurement, typically representing an area of only one mm^2. The position of the temperature probe is also critical. If the probe lifts only slightly off the surface, the temperature reading is erroneous. The application of infrared cameras addresses some of these issues, but these cameras only measure the surface temperature of the object, unless it is quickly sliced and evaluated, thus destroying the sample.

Another parameter which can be measured is the heat or caloric output of the susceptor, as in the method developed by Huang [1988]. This method measures the heat that a suscep-

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tor delivers to a load when exposed to a microwave field, thus giving an indication of the caloric potential. In many cases, the caloric output of a susceptor can yield data that is more useful than a temperature profile. Methods used to determine caloric output will provide a more uniform measurement of the susceptor heating capabilities by representing an average value over time, across the entire surface rather than at one point, as in surface temperature measuring. The heat output of the susceptor can be of value when trying to understand differences between susceptors, or the relation of susceptor performance when a food load is present.

The Huang [1988] method, the output of which was termed heat flux, measures the heat energy that is generated by a susceptor in a microwave field and absorbed by a heat transfer oil. The susceptor film is wrapped around a glass test tube containing a given amount of heat transfer oil. The oil is inert to microwave energy, meaning it does not absorb microwave energy and heat itself. A fluoroptic probe is used to monitor the change in temperature of the oil as it is heated by the susceptor. This change in temperature is then used to determine the calories generated by the susceptor. One limitation is that this test assumes the oil to be vigorously in motion so that it has a uniform temperature at any time otherwise samples that heat slow will result in a temperature gradient in the oil, while rapid heating susceptors would have little to no gradient, thereby confounding comparisons. Another limitation of this test is that the susceptor must be wrapped tightly around the test tube for good surface contact. Because of this, only very thin susceptors (less than 0.15 mm thick) can be used since the radius of the test tube prevents the use of thick and rigid susceptors.

The objective of the present paper is to show an alternative method to measure the caloric output of a susceptor which would provide a more general but still simple way of determining differences in susceptor performance without and in the presence of a food load.

Method

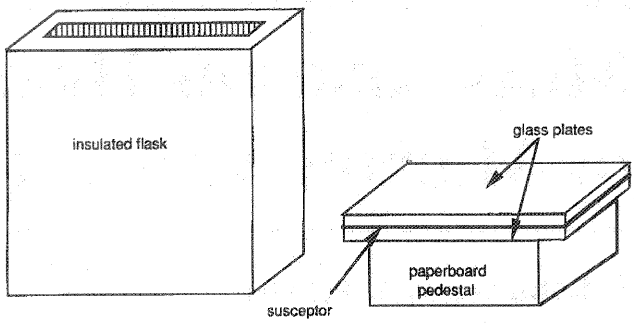

FIGURE 1: Proposed heat output test setup.

Figure 1 shows the set up for the test system. A susceptor sample (10.2 cm x 10.2 cm) is placed between two pyrex glass plates of the same dimensions and 0.47 cm thick and then exposed to microwave energy for a given period of time, e.g. 30 sec. at 725 Watts [IEC, 1988] using a standard microwave oven. As the susceptor heats, it transfers the heat energy to the glass. The glass plates are assumed to be essentially transparent to microwave energy. Since the same glass plates were used in each test, any effect of their heating would be constant throughout all experiments. The change in temperature of the plates is thus due to a small amount of energy created by microwave heating and the energy transferred from the heating susceptor.

Two susceptor materials were tested which included: (1) vacuum deposited aluminum on 48 gauge polyethylene teraphthalate (125 ohm) and backed on 0.3 mm thick paperboard; and (2) an experimental susceptor consisting of a printed ink of carbon black pigment on a paper backing, about 0.1 mm thick.

After heating, the plates are immediately immersed in an insulated flask containing a weighed amount of a heat transfer medium of known temperature. In this study distilled water was used. The water and glass are allowed to equilibrate (with water this takes about one minute) and the change in the temperature of the system is determined. The loss of heat by radiant heat and convection from the surface of the plates during both heating in the microwave and transfer to the flask is assumed to be small. The former is true since the convective flow of air within the microwave oven is small leading to a low heat transfer coefficient. The second issue will depend on the efficiency with which the glass plates are transferred to the flask. If the test is done the same way each time, these losses should be relatively constant.

A change in temperature represents a change in heat energy, Q, which is quantified by the thermodynamic equation;

$$\Delta Q = mC_p\Delta T \qquad (1)$$

where m is mass, C_p is the heat capacity at constant pressure, and ΔT is the change in temperature.

In the present system, the overall change in heat energy being measured is the sum of the two component energy changes and is represented by Equation 2;

$$\Delta Q_t = \Delta Q_g + \Delta Q_w = (mC_p\Delta T)_g + (mC_p\Delta T)_w \qquad (2)$$

where the subscripts g and w represent glass and water respectively. The C_p of the glass is 0.2 cal/g°C and that of water is 1.0 cal/g°C. The initial temperature of the two components of this test are set equal at room temperature. Because the glass and the water come to thermal equilibrium, their final temperature is also the same, thus the total change in temperature is equal. This change in heat energy can be equated to the heat output of the susceptor since the energy input is solely from the heat generated by the susceptor. Therefore the heat output, Q, of the susceptor is equal to ΔQ_t and can be standardized by dividing by the surface area of the susceptor sample, A.

$$Q = \Delta Q_t / A = \text{calorie/cm}^2 \tag{3}$$

Since the reported result does not take time into account, it is not a determination of heat flux (W/m^2), however, it is important that the microwave exposure time be referenced, because heat output is not constant with time.

Two small pieces of masking tape were used to hold the glass plates together to prevent movement and to ensure intimate contact with the susceptor throughout the test.

The sample was placed in a Gerling Lab oven (Sanyo; 1.3 ft^3) and elevated off the bottom tray using a paperboard pedestal; 7.6 cm in diameter by 3.5 cm high. This was to prevent loss of heat energy to the tray. Heating times were set at 30 seconds. When the heating cycle continues for longer periods, the glass plates become sufficiently hot that when immersed in the water, boiling of medium can occur. This would lead to a loss of heat that is difficult to quantify, however an alternate fluid, such as ethylene glycol, could be used instead of water to get around this problem.

The insulated flask used to hold the fluid was a block of closed cell polystyrene, measuring about 15 cm x 15 cm x 5 cm. A well, measuring 12 cm x 1.5 cm x 11 cm deep was bored out of this block. The heat transfer medium used was 100 grams of distilled water ($C_p = 1.0$ cal/g°C). This was just enough to just submerge the plates completely and not cause any of the fluid to overflow out of the flask. The initial temperature of the water and the glass plates was at room temperature (~21 °C).

After heating in the microwave oven, transferring and immersing the plates, the water was stirred to distribute the heat and facilitate its transfer from the glass to the water. After about one minute, the final temperature was determined by taking readings in several places within the well and averaging to ensure equilibrium was reached. Using the above information, Equations 2 and 3 become:

$$Q = \frac{(151\ \text{g})(0.2\ \text{cal/g})\Delta T + (100\ \text{g})(1.0\ \text{cal/g})\Delta T}{(10.2\ \text{cm})^2} \tag{4}$$

or

$$Q = 1.26\Delta T \tag{5}$$

Results

Figure 2 illustrates the surface temperature profile of the two susceptors studied when exposed to 725 Watts [IEC, 1988] of microwave energy in an empty oven cavity. The temperature profiles represent the surface temperature of the susceptor as measured by a fluoroptic probe. Although they do not heat at the same rate, they do reach about the same maximum temperature of 200°C after one minute of healing. Based on this data alone, one may think that the two susceptors would behave similarly in heating of a food load. However, Figure 3 shows that when a food load (50 g frozen fish fillet) is placed in contact with the susceptor, the temperature response between the two susceptors is very different. This was measured by forming the susceptor into a sleeve and placing the fish within. Fluoroptic temperature probes were inserted between the fish and the metallized surface of the susceptor. The printed susceptor failed to heat above 100°C. This test is probably a better representation of the susceptor's performance.

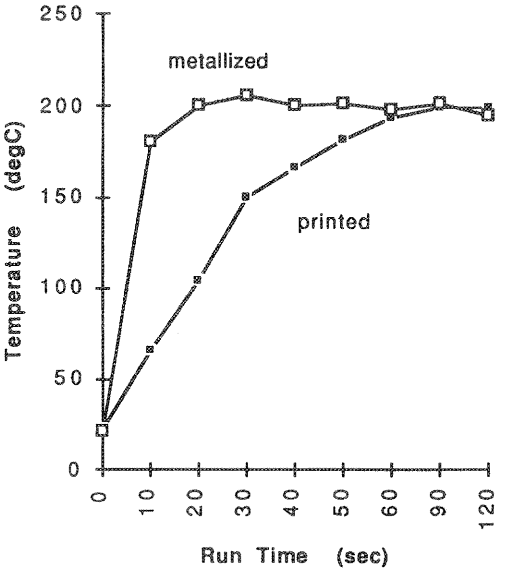

FIGURE 2: Temperature profile comparison of metallized and printed susceptors; 725 Watts.

Table 1 shows the average caloric output, based on triplicate tests, of these same susceptors as measured by the proposed heat output method. The printed susceptor generates less than one third of the calories of the metallized susceptor which is consistent with the results of Figure 3, indicating that the heat output measurement better predicts the response found in a real use situation.

As another illustration of using this method to measure

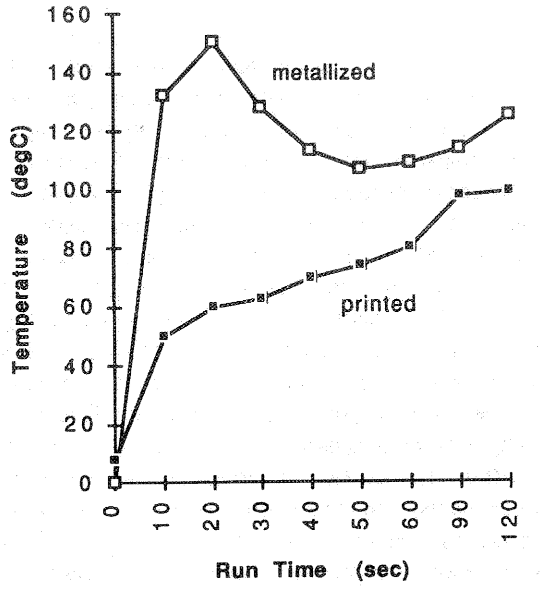

FIGURE 3: Temperature profile comparison of metallized and printed susceptor with frozen fish load present; 725 Watts.

TABLE 1.
Magnitude of the heat output of a metallized vs. printed susceptor

	heat output (cal/cm^2/30sec)
metallized	27.9 ± 0.51^a
printed	9.4 ± 0.26

^{a} ± standard deviation n = 3

heat output, a two by two design, examining the variables of susceptor resistance and backing thickness was performed. Susceptor samples were vacuum deposited aluminum on 48 gauge polyethylene teraphthalate. An exposure time of 30 seconds in a Gerling (Sanyo; 1.3 ft^3) laboratory microwave oven at 725 Watts [IEC, 1988] was used.

Results shown in Table 2 indicate that, using this method, susceptor performance, due to resistance and backing thickness, can be differentiated. Increasing the resistivity and reducing the thickness of the backing appear to increase the heat output of the susceptor. These values are statistically different from each other at the 90% level ($p < 0.10$). However, the chances that these small differences will make a meaningful difference in product quality may be quite small.

The study illustrates a simple method to measure susceptor heat output. This, with other tests, should assist the food product and packaging developer in selecting the proper susceptor.

TABLE 2.
Influence of resistance and thickness on heat output of metallized susceptors.

Resistance	Thickness	Heat Output (cal/cm^2)
25 ohm	13 mm	24.9 ± 1.60^a
125 ohm	13 mm	27.9 ± 0.51
25 ohm	61 mm	20.4 ± 0.64
125 ohm	61 mm	22.6 ± 0.35

^{a} ± standard deviation n = 3

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