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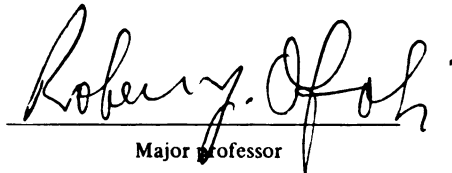
Thermally Induced Migration Of Food  
Packaging Materials Into Foods During  
Microwave Heating

presented by

Siti Noorbaiyah Abdul Malek

has been accepted towards fulfillment  
of the requirements for

Masters degree in Food Science

  
Major professor

Date 7/2/90

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**THERMALLY INDUCED MIGRATION OF FOOD PACKAGING MATERIALS  
INTO FOODS DURING MICROWAVE HEATING**

**By**

**Siti Noorbaiyah Abdul Malek**

**A THESIS**

**Submitted to  
Michigan State University  
in partial fulfillment of the requirements  
for the degree of**

**MASTER OF SCIENCE**

**in**

**Food Science**

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**1990**



**ABSTRACT****THERMALLY INDUCED MIGRATION OF FOOD PACKAGING MATERIALS  
INTO  
FOODS DURING MICROWAVE HEATING****By****Siti Noorbaiyah Abdul Malek**

The effect of temperature at the interface of two microwaveable containers (a susceptor material and a CPET laminated tray) on the migration of four compounds were studied using the method proposed by the Food and Drug Administration (FDA). Corn oil was used as a food simulant, and was microwaved for 1 to 7 minutes in both containers. The temperature at the interface of the oil and the containers were recorded. Extracts of the oil were then analyzed by a HPLC system.

Temperatures at the interface of the susceptor material increased 3 to 4 times faster than in the CPET tray under identical exposure times. The highest temperatures attained in the susceptor material after 1 to 7 minutes of exposure were 136.4°C, 186.0°C, 196.6°C, 205.4°C, 217.8°C, 225.0°C, and 244.8°C, respectively. The highest temperatures attained in the CPET tray were 34.1°C, 45.8°C, 59.9°C, 73.6°C, 78.9°C, 75.6°C, and 81.9°C, respectively.

Dimethyl terephthalate (DMT), diethyl terephthalate (DET), bis-(2-hydroxyethyl)

terephthalate (BHET), and polyethylene terephthalate cyclic trimer were all found to have migrated into the oil heated in the susceptor material. No migration was observed in the oil heated in the CPET tray. The concentration of all components increased with temperature at the interface. The highest concentration of BHET, DMT, DET, and Cyclic Trimer were  $41.9 \mu\text{g}/\text{dm}^2$ ,  $361.5 \mu\text{g}/\text{dm}^2$ ,  $343.6 \mu\text{g}/\text{dm}^2$ , and  $12300 \mu\text{g}/\text{dm}^2$ , respectively.

**To Ikmal, Fariz, Apak, and Mummy**

## **ACKNOWLEDGEMENTS**

### ***IN THE NAME OF ALLAH, THE MOST MERCIFUL AND THE MOST BENEFICIENT***

Alhamdulillah (Praise be to Allah). Lord of the Universe. The mercy-giving, The Merciful! Ruler on the Day of Repayment, You do we worship and You do we call on for help. Guide us along the straight road, the road of those whom You have favored, with whom You are not angry, nor who are lost. [Amen.]

I would like to extend my gratitude to my sponsors, the Government of Malaysia and the MARA Institute of Technology, for giving me this valuable opportunity to further my studies here in the United States of America. I hope I have fulfilled the trust and hope that they put in me to gain knowledge in order to help fulfill the dreams of betterment of our people and country.

'Terima kasih banyak-banyak' to my major professor, Dr. Robert Ofoli for all the unselfish advice, help, guidance, kind thoughts and pep talks given during the duration of my program. I am also indebted to him and his family for their assistance and understanding through some of the difficult times that I went through during my stay here.

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## **CHAPTER 1**

### **INTRODUCTION AND OBJECTIVES**

**Making products that are microwaveable is an important current thrust of the food industry. This is spurred by demands for consumer convenience and changes in demographics and lifestyles. For example, there are more women in the work force, a smaller number of people per family, dual-income families, and single parent homes. All of these factors have caused the sales of microwave ovens and microwaveable foods to rise dramatically.**

**Since its introduction in 1967, the microwave oven has experienced exponential growth. In 1986, 40% of U.S. homes (Rosenkranz and Higgins, 1987) and 20% of British homes (Guise, 1986) owned a microwave oven. And in the 1990's, it is estimated that the saturation of microwaves in United States homes will be close to 90% (Anon, 1988). Figure 1 shows the number of microwave ovens shipped and the share of microwaveable foods in the food market in the United States (Huang, 1987). The number of microwave ovens shipped increased by a factor of 10 from 1 million units in 1978 to about 10 million units in 1988. Sales of microwaveable packaged foods were in the vicinity of \$4.5 billion in 1986, up from about \$500 million in 1980, representing an increase of 800% over the five year period.**

**According to Productscan Database (Marketing Intelligence Service), over 8% of the roughly 2,500 new food products introduced in 1986 were targeted as microwaveable. This is about double the number in 1985 (Rothenberger, 1987). This figure would**

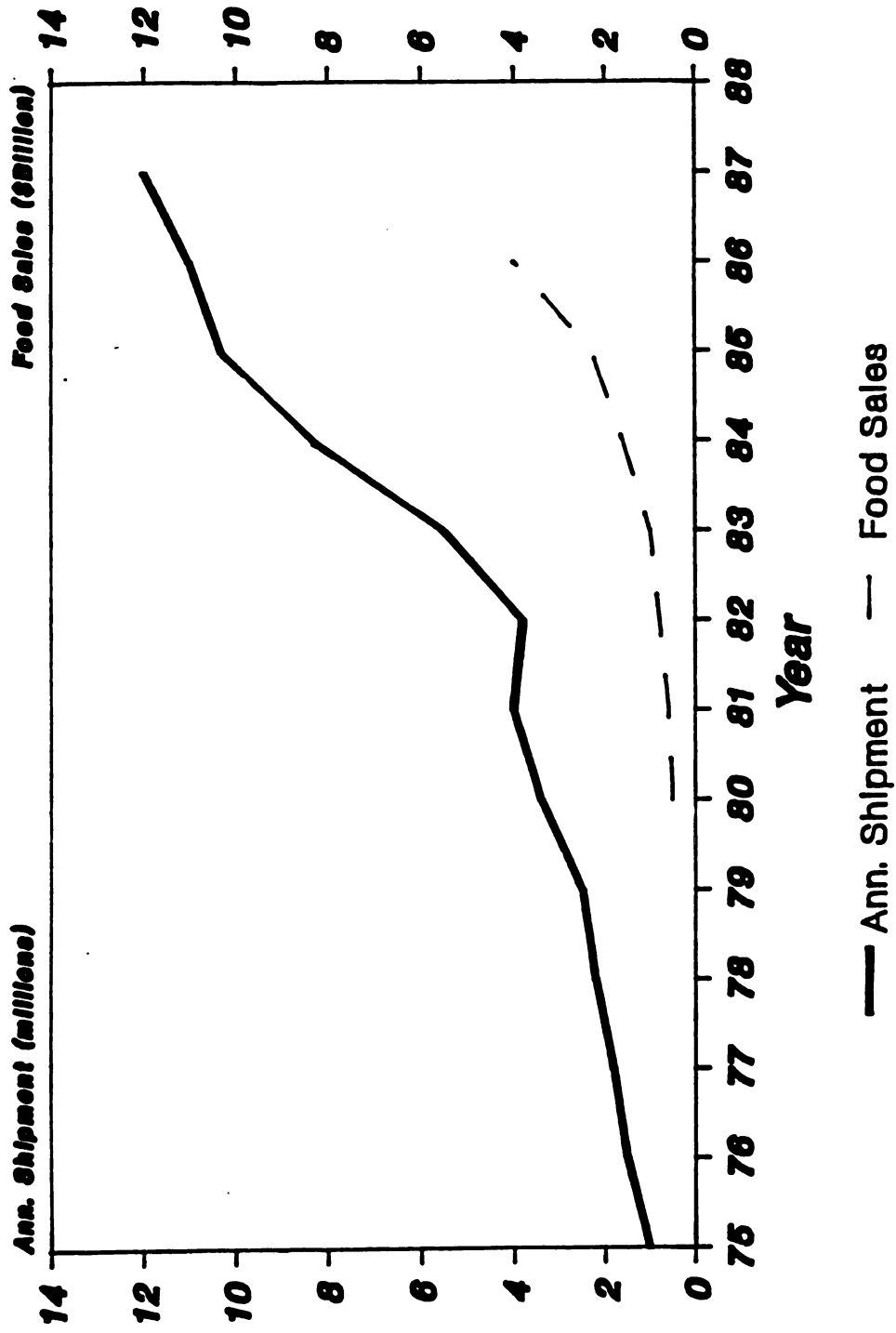


Figure 1. Sales of microwave ovens and microwaveable foods in the United States.  
(Source: Huang, 1987)

probably be increased further since foods which were formerly packaged for conventional preparation are now appearing in containers for use in both conventional and microwave ovens (Anon, 1987). Among the foods that will experience growth in the microwaveable packaged foods market, microwave packaged frozen foods are expected to have a 14% growth rate, and shelf stable foods were expected to grow at an explosive rate of 73% (Rosenkranz and Higgins, 1987).

In spite of the growing use of microwave ovens and microwaveable foods, development of cookware for microwave ovens is lagging. This is primarily due to the limited number of materials that can be safely used in a microwave oven. Most of the packages used in the market use either polyethylene terephthalate (PET) or crystallized polyethylene terephthalate (CPET). These materials are heat tolerant and have excellent mechanical properties. PET in its amorphous state has a heat resistance range lower than its glass transition temperature, which is about 98°C. In the crystallized form, it is more heat stable and can tolerate temperatures of up to 177-205°C (Wright, 1984).

Due to the lack of microwaveable utensils, home-owners and microwave users have been using household items such as aluminum foil, metal pans, plastic cups, bowls, trays and plastic wraps in the microwave oven. Aluminum foil and metal pans are ideal for conventional ovens, but are not recommended for microwave ovens for use with foods because improper use can cause arcing in the microwave oven. And, using household plastic in the microwave oven may expose the material to thermal conditions beyond what they were originally approved for use by the Food and Drug Administration (FDA) (Bishop and Dye, 1982).

Most household plastics are not suitable because of the high temperatures attained in microwave ovens. It was previously believed that temperatures of foods heated in

microwave ovens did not exceed 100°C. However, there have been instances where consumers have reported popcorn bags catching fire during heating in microwave ovens (McCowin and Brown, 1988). This indicates that the temperature had exceeded 232°C, the temperature at which paper or wood fibers ignite. Recent evidence has indicated that localized package temperatures may be in excess of 260°C in microwave ovens, especially with the new susceptor packages that are used for browning and crisping (Borodinsky, 1988).

With the increasing use of these materials, the FDA has expressed concerns about food-package interactions, especially with respect to the migration of packaging components into foods. Even though these plastics will not melt, it has been known that additives in the plastics migrate at high temperatures into the food material (Bishop and Dye, 1982).

The purpose of this study was to determine if there was any migration of substances from the material to the food during elevated heating (200-260°C) in a microwave oven and to identify and quantify these migrants. The specific objectives are:

1. To determine the effect of temperature on the migration of components of packaging materials into foods; in particular, to correlate the temperature at the interface of the product and the container to the level of migration observed.
2. To do a comparative study of migration levels of four major migrant components from two packaging systems.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

The design of food products and packages for use in a microwave oven presents a challenge to food and packaging scientists. To develop high quality products and packages, one must first understand the heating behavior of foods in the microwave oven, and how packaging materials influence and are influenced by the microwave fields.

Some of the areas that need special attention are the development of packaging systems that can provide evenness of heating and reconstitution temperatures in foods to provide microbiologically safe preparation, design of safety features for handling packages that are to be opened while hot, and release of indirect food additives from the packaging materials at elevated temperatures (Perry, 1987a).

#### **2.2 Microwave Heating**

##### **2.2.1 Microwave radiation**

Microwave is a form of electromagnetic radiation; that is, its mode of heating is via a radiant process. It is located between the radio and infra-red regions in the electromagnetic spectrum, and has a frequency of  $10^9$  Hertz (Hz) as shown in Figure 2



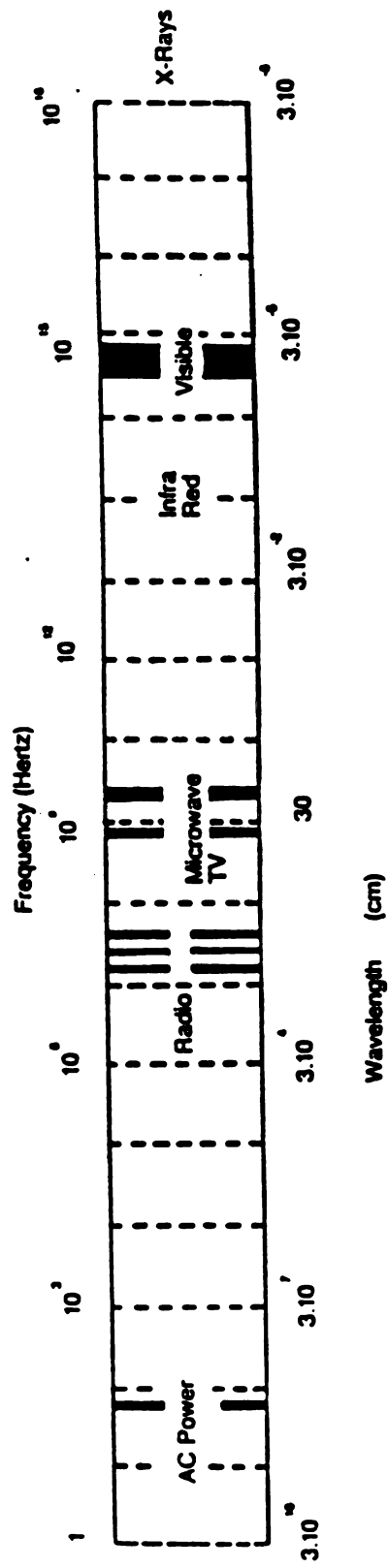


Figure 2. The Electromagnetic Spectrum  
(Source: Dixon et al., 1988)

(Dixon et al., 1988). Almost all household microwave ovens operate at one of two frequencies: 915 MHz and 2450 MHz. In air, this corresponds to a wavelength of about 12.24 cm.

The wavelength is related to the frequency by:

$$\lambda = \frac{c}{\nu} \quad (1)$$

where  $c$  is the speed of light ( $3 \times 10^{10}$  cm/s),  $\nu$  is the frequency (Hz) and  $\lambda$  is the wavelength (cm).

Microwave radiation has an electric (E) and a magnetic (H) component (Figure 3). The electric and magnetic components oscillate in the form of sine waves perpendicular to each other at  $2.45 \times 10^9$  cycles per second (2450 MHz) and  $9.15 \times 10^8$  cycles per second (915 MHz), respectively. In a microwave oven, the electric component interacts with the positive and negative charge regions of materials with molecular dipoles (eg. water) causing them to rotate at the same frequency so as to realign themselves to the rapidly changing electric field. The motion created by these molecules disrupts the hydrogen bonds between neighboring molecules, causing the food to be heated by frictional energy (Mudgett, 1989).

Positive and negative mobile ions or electrons (eg. salts, oils and fats) are also affected by the electric component of the field. The mobile ions migrate towards oppositely charged regions of the electric field, again disrupting the hydrogen bonds and generating heat (Mudgett, 1989). Oils and fats have components that couple with the

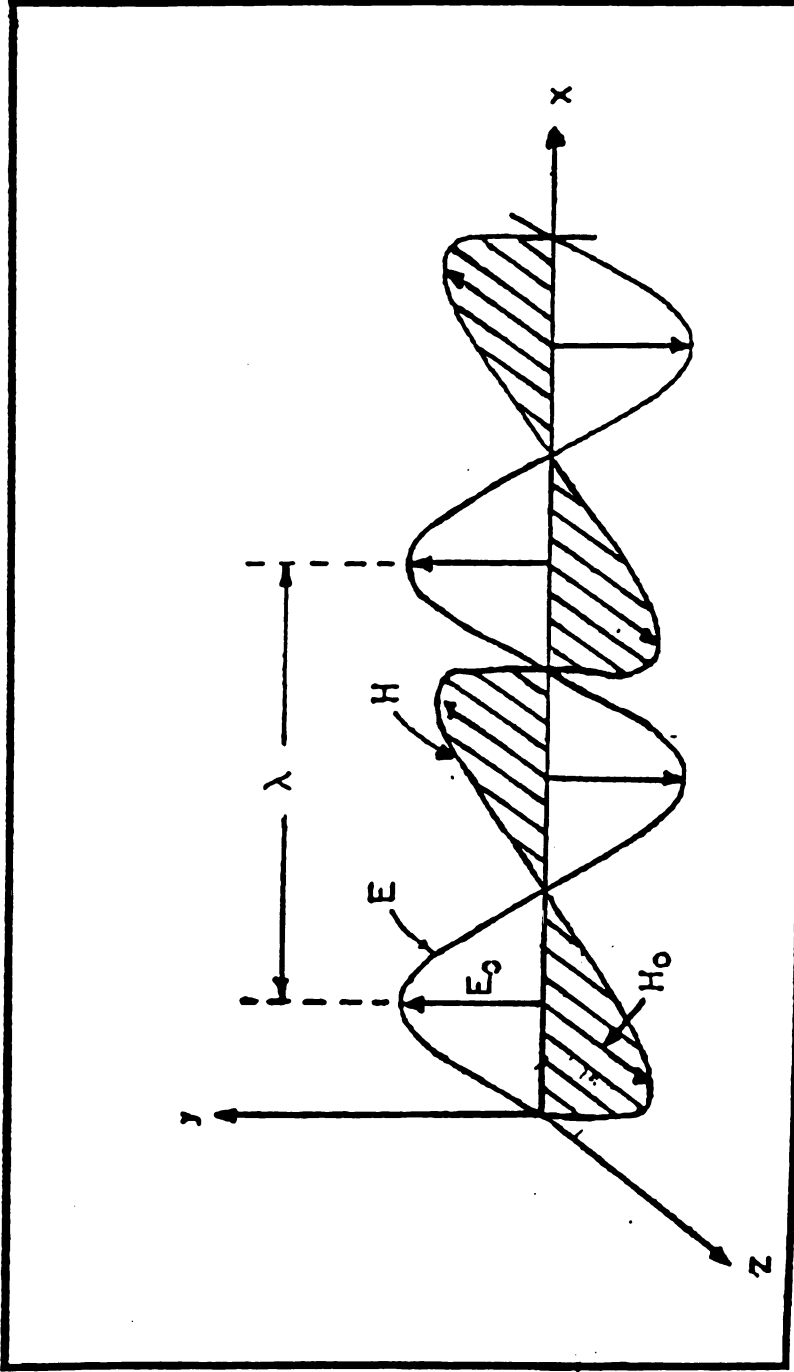


Figure 3. A plane monochromatic electromagnetic wave.  
(Source: Rothenberger, 1987)

electric component of the microwave that causes it to heat upon exposure.

### **2.2.2 Dielectric Constants and the Loss Tangent**

The heating of foods in a microwave oven depends on the dielectric properties of the foods. The two important constants that define the dielectric properties of materials are the relative dielectric constant (relative to free space) and the loss factor. The dielectric constant,  $\kappa'$ , is the measure of a material's ability to store electrical energy. The loss factor,  $\kappa''$ , is a measure of how effectively the food dissipates microwave energy throughout the material. The greater the dielectric constant of the food material, the slower the velocity of the microwave through the food. This effect is more pronounced at the interface of the food material and air. If the dielectric constant of the food is very large compared to air (dielectric constant of air is 0), the microwave will be reflected off the surface of the food. This is the reason why most foods do not generally brown or get crisp in the microwave oven (Keefer, 1986).

The ratio of the dielectric loss to the dielectric constant is defined as the loss tangent:

$$\tan \delta = \frac{\kappa''}{\kappa'} \quad (2)$$

The loss tangent is related to the material's susceptibility to penetration by microwave radiation, and its ability to dissipate electrical energy as heat (Mudgett, 1986). The dielectric properties of food and other biological materials at microwave frequencies may be determined by their moisture, solid and salt content (Swami and Mudgett, 1981).

## **2.3 Types of Microwave Packages**

Packages for microwave ovens can be grouped into four categories: a) transparent, b) absorbing, c) shielding, and d) field modifying. Each of these categories is described in detail below.

### **2.3.1 Transparent Materials**

Like the name implies, these packages are transparent to electromagnetic waves. The waves penetrate the material to the food where they are absorbed, resulting in direct heating of the products. These type of packages are suitable for liquid foods such as sauces, vegetables, soups, etc. Heating is more uniform in these types of packages if they are closed, because the trapped water vapor can enhance the heating of the product. As long as water is present and atmospheric pressure is maintained, the temperature in the container will be 100°C at the maximum. Some of the polymers used in this category are polyethylene, polypropylene, polyester, nylon and paper products (Perry, 1987b).

### **2.3.2 Absorbing Materials**

These materials are used to brown and crisp food by coupling with the electric component of the microwave radiation. Collectively, these materials are called "susceptors." Turpin (1980), the inventor of susceptor material technology, defined it as a material that absorbs microwave energy by coupling with the electric field component of the microwave radiation and through resistive heating in the thin metal film, microwave energy is converted into sensible heat. This sensible heat warms the product surface in contact with it by conventional thermal conduction, thereby promoting browning and crisping in the food product.

Basically, the material consists of a thin layer of metal vacuum deposited on a heat-set plastic carrier film (Figure 4). In most common types, aluminum is deposited on a 48 gauge oriented polyethylene terephthalate (PET) film which is then laminated with adhesive onto a paperboard for structural rigidity. Apart from providing a heat resistant substrate for metallization, the polyester layer is also suitable for food contact. During heating of the food, the metallized surface is away from the food for two reasons: 1) to protect the aluminum from chemical or physical damage from food components, and 2) to prevent the aluminum from becoming an indirect food additive (Perry, 1987b).

### **2.3.3 Shielding Materials**

Shields are metallic structures that are thick enough that they reflect microwave energy, without getting heated. Shielding materials can be used in a microwave oven to prevent electromagnetic waves from reaching a product or parts of a product. For example, in a multi-section one meal tray, which contains a main course and a dessert in the same tray one would want the main course (eg. meat) to be hot and the dessert to remain cool. By using the shielding material, the electromagnetic fields can be directed away from the dessert section to the main course section.

A shield can be aluminium foil, foil laminated to a substrate, or any metal sheets such as aluminium pans and trays. Even though these materials can be used in the microwave oven, their use requires special precautions to avoid arcing. Arcing results when a wave is reflected off the edge or corner of a metallic surface, and can cause damage to the magnetron if the waves are reflected towards it. Shields can also cause a

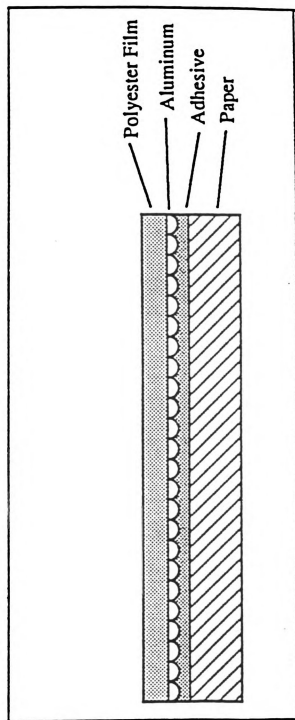


Figure 4. A cross-section view of a susceptor material  
(Source: Anon., 1988)

large electrical potential build-up on the shielding material. If this area comes into contact with a grounded surface or another shielding material at a different potential, this can cause an electric spark in the oven.

Arcing can be controlled by several methods: by coating the foil with a non conducting electrical insulator, heating metal pans inside their paperboard carton, or designing packages that give a uniform electric component to prevent build up of electric potential (Perry, 1987a).

### **2.3.4 Field Intensifying Materials**

These packages focus and intensify the microwave field in a manner similar to a lens; they focus microwave energy in the same way a lens focuses light (Rosenkranz and Higgins, 1987). This packaging system allows modification of the electromagnetic fields to provide a) uniform heating, b) selective heating, c) browning and crisping, and d) arcing prevention. This technique is best represented by the "micro-match" package of Alcan Canada Product, Ltd. (Keefer, 1986). Their system utilizes a high technology lid structure and an aluminium base. The lid contains active components, which are used to generate intense fields at the surface of a food material that requires browning and crisping. For selective heating, these active components balance the heating distribution of a multi-component meal tray (Figure 5).

Figure 6 shows the comparison of the temperature differentials of a "micro-match" container with a transparent and an aluminium container. The temperature differentials across the food heated in the field intensifying container is much more even than in the others. For more uniform heating, the active component in the oven acts as a mode-stirrer, and allows better distribution of heating across the container (Keefer, 1986).



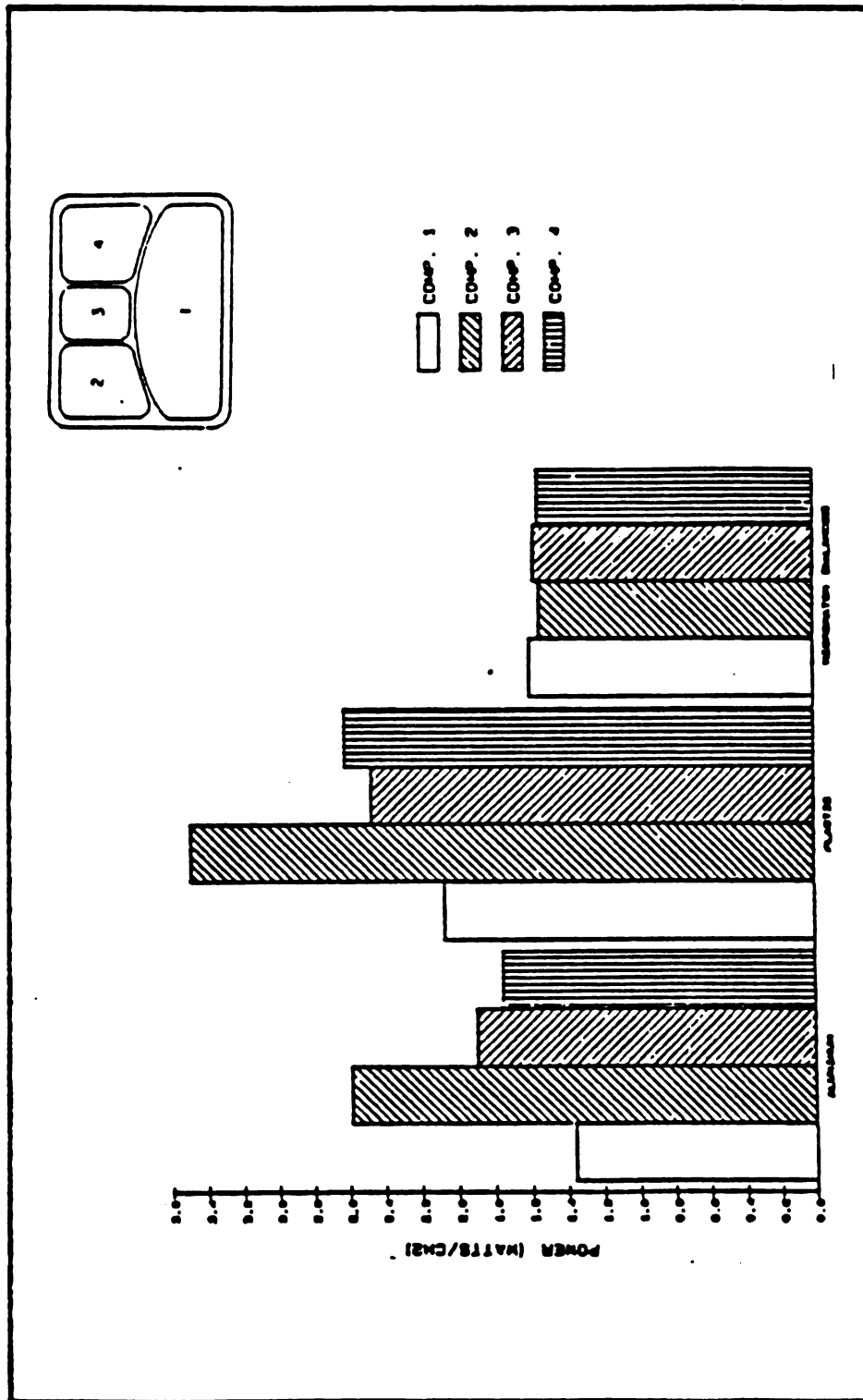


Figure 5. Selective heating in a microwaveable multi-component container.  
(Source: Keefer, 1986)

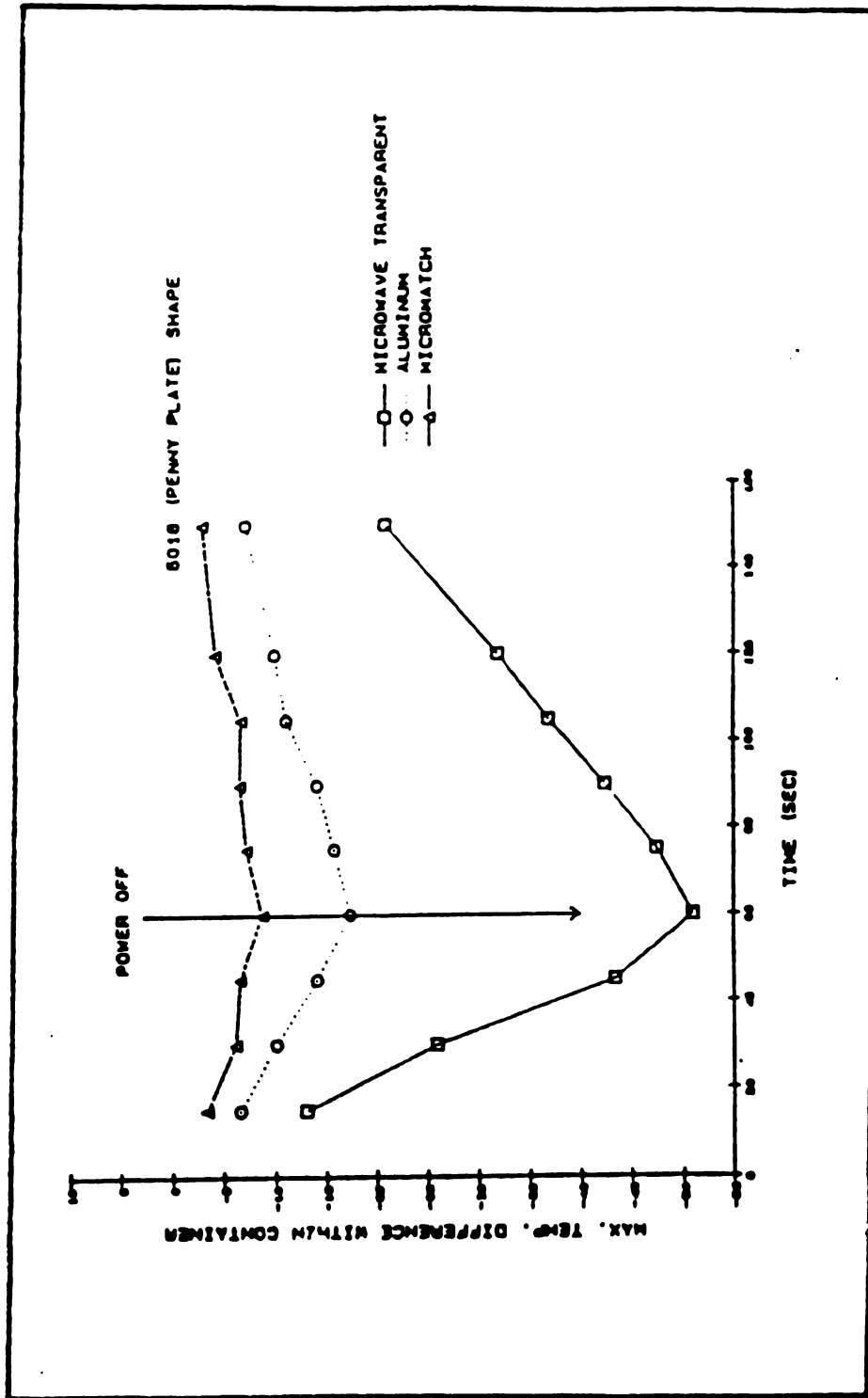


Figure 6. Time-temperature differentials between three microwaveable containers.  
(Source: Keefer, 1986)

## **2.4 Migration of Packaging Components**

### **2.4.1 Introduction**

Migration is the generic term given to the transfer of a substance from the polymeric matrix to the food. The substances include monomers and low molecular weight residues, processing aids (lubricants, antislip agents and antistatic agents), plasticizers, adhesives, and additives (antioxidant, colorants, etc.; Bishop and Dye, 1982). The following may produce off-flavors in the food as well as additives that may represent a toxic hazard to consumers: vinyl chloride (Bartsch et al., 1976), acetonitrile (Di Pasquale, 1978; McNeal et al, 1979; Gilbert and Startin, 1982) and esters of phthalic acid (Lawrence et al., 1975).

### **2.4.2 Global and Specific Migration**

There are two types of migration: **global** and **specific**. Global migration refers to the total transfer or migration of all species from the package to the food. It relates to the transfer of all substances to the food whether they are toxic or not. Specific migration relates to one or more identifiable substances (eg. a particular monomer) that are constituents of the packaging material (Giacin, 1980).

Total or global migration can be measured by weight differences. This consists of placing a sample of a material of known surface area in contact with an appropriate food simulant or solvent under defined time-temperature conditions (Anon, 1976) and determining total transfer by weight difference.

The limits of specific migration are defined by those compounds known or deemed potentially hazardous to human health; no account is taken of the total quantity of other

migrants transferring into the contact phase. Determination and quantification of specific migration varies with the type of migrant of interest. Several methods are discussed in detail in Giacin and Brzozowska (1985) and Crompton (1979).

### **2.4.3 Direct and Indirect Additives**

Migration can either be direct or indirect. Direct additives are substances added directly to the food or packaging materials. Examples include antioxidants added to cooking oil and cereal boxes to prevent oxidation or rancidity. Indirect additives are those substances that are found to migrate from the package to the food. Both direct and indirect additives are regulated equally by the same statutes, the 1958 Food Additives Amendment of the Federal Food, Drug and Cosmetic Act of 1938. Federal regulations which apply to food package components are listed in Table 1 (Risch, 1988).

### **2.4.4 Theoretical Considerations**

#### **2.4.4.1 Mass Transfer in Polymeric Films**

The movement or transfer of a migrant through a polymeric film can be described by three generalized mass transfer models which are represented schematically in Figure 7 (Gilbert et al., 1980).

The migration of a component from a package mass to the food is basically a desorption process which depends on the diffusivity of the migrating species. Diffusivity is defined as the tendency of a substance to permeate through the polymer bulk phase. The diffusion process is described by Fick's first law:

**Table 1. Federal regulations on food packages and package components.**

| <b>Code of Federal Regulation Citation</b> | <b>Topic</b>                                                            |
|--------------------------------------------|-------------------------------------------------------------------------|
| 21 CFR Part 170                            | Food additives                                                          |
| 21 CFR Part 172                            | General information on indirect food additives                          |
| 21 CFR Part 175                            | Indirect food additives: adhesives, coatings and components of coatings |
| 21 CFR Part 176                            | Indirect food additives: paper and paper components                     |
| 21 CFR Part 177                            | Indirect food additives: polymers                                       |
| 21 CFR Part 178                            | Indirect food additives: adjuvants, production aids and sanitizers      |
| 21 CFR Part 179                            | Irradiation in production, processing and handling of food              |
| 21 CFR Part 181                            | Prior-sanctioned food ingredients                                       |
| 21 CFR Part 182                            | Substances GRAS*                                                        |
| 21 CFR Part 186                            | Indirect food substances, GRAS                                          |

(Source: Risch, 1988)

\*Generally Recognized As Safe

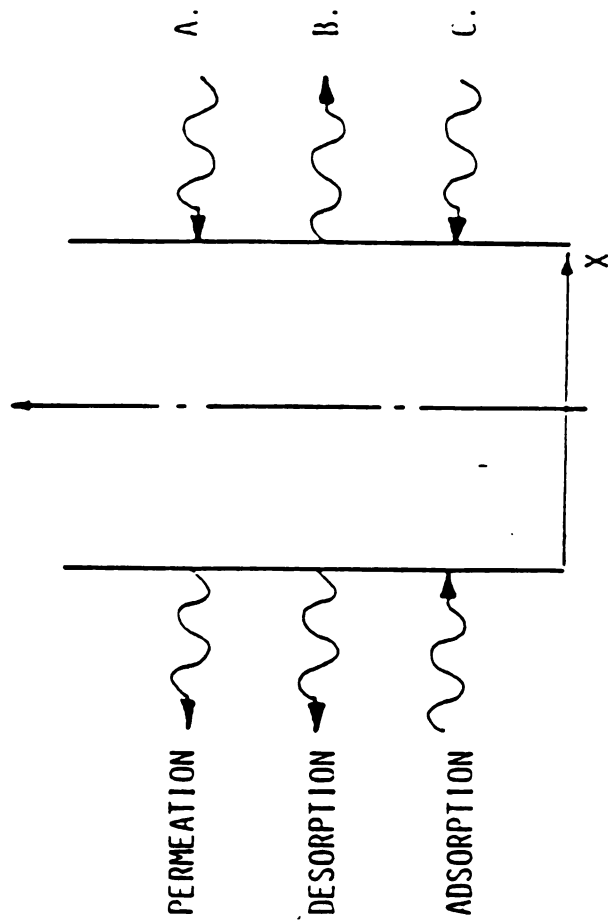


Figure 7. Schematic of diffusion mechanisms.  
(Gilbert et al., 1980)

$$\frac{\partial m}{\partial t} = -DA \frac{\partial c}{\partial x} \quad (3)$$

where  $c$  is the migrant concentration in the polymer,  $D$  is the diffusion coefficient of the species in the polymer,  $m$  is the mass of the component transferred,  $t$  is the time taken for the species to diffuse,  $A$  is the area of the plane across which diffusion takes place, and  $x$  is the path of diffusion (Crosby, 1981).

Fick's second law describes the diffusion process over an infinite surface area (that is, diffusion from a sheet):

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \quad (4)$$

where  $x$  is the distance measured from the polymer-contacting interface into the polymer. Migration is, therefore, a mass transport process under defined secondary conditions (i.e. time, temperature, and nature of the contact phase). The driving force for mass transport processes is the concentration difference or gradient, where dissolved species diffuse from a region of higher concentration to a region of lower concentration.

For desorption to occur, the migrant will have to undergo two processes in succession: 1) diffusion of the migrant to the polymer surface, and 2) subsequent desorption of the migrant accumulated at the surface to the contact phase.

In addition, the desorption of a migrant through a polymer to a contacting phase can be considered a function of the polymer-migrant interaction affinity and diffusion. The affinity of the polymer-migrant interaction will determine the equilibrium amount of migrant transferred to a contacting phase (Giacin, 1980). Thus affinity becomes

increasingly important as the migrant concentration decreases because diffusion of the migrant through the polymer will affect the rate at which equilibrium is attained (Gilbert, 1976).

Briston and Katan (1974) described three packaging material contact phase systems in terms of migrant diffusivity: 1) non-migrating 2) independently migrating, and 3) leaching. In system 1, transfer of the components occurs only from the packaging surface. The diffusion coefficient approaches zero, and cannot be measured. In system 2, the diffusion coefficient can be measured under the time-temperature conditions of the study. This system normally applies to volatile components such as monomers and, in some cases, plasticizers and antioxidants. In this system, the rate and amount of migrant transferred depends on the contact phase volume and boundary layer resistance in the extracting phases at the time of desorption, especially for components that tend to partition strongly toward the polymer phase (Giacin, 1980). In system 3, components of the contacting phases, such as solvents, penetrate into the polymer and cause swelling and disorientation of the polymer structure. This plasticizing effect enhances the diffusivity of the migrant, resulting in an increased rate of migration.

#### **2.4.5 Review of Migration Studies**

Much work has been done on the migration of additives from packaging materials into foods. Giam and Wong (1987) has compiled an extensive list of studies done on the migration of different plasticizers into foods and pharmaceutical products. Others who have also researched the migration of plasticizers from food packages into foods include Startin et al. (1987), Castle et al. (1987, 1988a, 1988b), and Bishop and Dye (1982). Miltz and Rosen-Doody (1984), Adcock et al. (1984), Withey and Collin (1978), and



Varner et al. (1983) have done studies on the migration of monomers and low molecular weight residues. Bieber et al. (1985) and Schowpe et al. (1987) conducted studies on migration of antioxidants, and Hotchkiss and Landois-Garza (1987), studied migration of aroma and flavor compounds from packaging materials.

To conduct a migration study, an extensive range of variables have to be considered. Many times, results from one group of researchers are difficult to relate to another group because of differences in choice of temperature and heating times. For this reason, the regulating bodies have recommended the time and temperature for use in migration studies.

One condition for accelerated migration studies is that the extraction tests should be run to equilibrium at a minimum temperature of 49°C for 10 days in a recommended extraction test cell using food simulating liquids in place of real foods (Anon, 1976): for example, water for aqueous food, 3% aqueous acetic acid for acidic food, 8% to 50% aqueous ethanol for alcoholic foods, and heptane for fatty foods.

There are, however, no regulations for adhesives, paper or plastics used in microwave ovens because when the laws were passed for these materials, they were used at temperatures not exceeding room temperature, and the regulatory agencies did not find it necessary to set an upper temperature limit. Now, with susceptor materials where temperatures can exceed 232°C, regulatory agencies are concerned about the thermal integrity of the package. Mitchell (1988) reported that studies conducted so far have indicated that there is evidence of cracking and melting of PET film and browning of the paperboard.

Many studies on migration of components from food packaging materials have been reported in the literature, as evidenced by some of the examples given in the

previous section. However, not much has been done in investigating the migration of packaging materials in microwaveable cookware. The few studies done so far have shown that migration does occur (Bishop and Dye, 1982; Startin et al., 1987; Dixon et al., 1988; and Heath and Reilly, 1981). With respect to susceptor materials, migration studies are in the process of being carried out by a few groups of researchers, including the FDA. The following is a discussion of some of the migration studies that have been conducted.

Studies on the migration of the plasticizer di-(2-ethylhexyl) adipate (DEHA) from packaging films in the microwave have been reported by Bishop and Dye (1982), and Startin et al. (1987). Bishop and Dye (1982) studied the migration of the plasticizer from a plastic wrap material after 10 minutes of exposure in the microwave oven. They used a vegetable oil to trap the escaped plasticizer and the oil was analyzed by gas chromatography. The average concentration of DEHA migrated from the plastic wrap was  $33.35 \text{ mg/dm}^2$ , equivalent to 23% of the weight of the plastic wrap used. The minimum quantity detected was  $1 \text{ ng/dm}^2$ . When they compared these results to samples of the same plastic wrap exposed to vegetable oil for 10 minutes at  $20^\circ\text{C}$ , no DEHA peak was produced from the oil sample.

Startin et al. (1987) studied the migration of DEHA from a flexible packaging film into a variety of foods during in-home use of PVC films for such purposes as covering the food during microwave reheating of cooked food. They found that migration of the compound did occur, and increased with increased contact time and temperature. It was also reported that the level of migration was highest where there was direct contact between the film and food with a high fat content at the surface. DEHA levels were

highest for microwave cooked meats (151 mg/kg for roast chicken and 351 mg/kg for pork spare ribs) and lowest for microwave cooked vegetables (3 mg/kg for carrots and 4 mg/kg for potatoes).

Heath and Reilly (1981) investigated the possibility of migration of the plasticizer acetyl-tributyl citrate (ATBC) from a plastic film into poultry meat and model food systems in a microwave oven, and reported significant migration. They reported that the amount of ATBC found in the poultry meat increased as the residence time in the microwave increased. The quantities migrated reached a plateau after about 8 minutes of cooking. In the model food system, they found that the lipid portion of the system contained most of the migrants and was responsible for the retention of acetyl tributyl-citrate in the sample. An increase in the lipid portion of the food system also increased the amount of ATBC found. They also found that the amount of food in contact with the film during cooking was an important factor which influenced the amount of ATBC transferred from the film.

Dixon et al. (1988) conducted another migration study using a thermoformed, microwaveable container made from polypropylene/Saran/polypropylene co-extruded material. Five components (2,5-dimethyl nonane, 2-methyl undecane, butylated hydroxytoluene (BHT), 5-ethyl-5-methyl decane, and 15C-hydrocarbon) were detected and quantified using a headspace gas chromatography procedure. They observed that the quantities increased with increased microwave exposure.

A small number of studies on the migration of components from susceptor materials have been reported. Preliminary test results conducted by the FDA on the effect of temperature on susceptor material in microwave ovens showed that susceptors can reach temperatures above 260°C during microwave heating Mitchell, (1988). Using a

dye test, it was observed that at this temperature, the film surface intended to be a barrier layer for food contact had cracks, and in some places the polyester film had already melted (Mitchell, 1988). The crack actually penetrated through to the paper and adhesive level below the food contact surface.

In another study, Lentz and Crosset (1988) of the Pillsbury Company conducted a test to determine the temperature at the interface of several foods (popcorn, pizza, fish fillets) in susceptor materials during microwave heating. In one of their tests, temperatures as high as 276°C and 265°C were recorded after 4 minutes at several places in a popcorn bag using Luxtron probes. The maximum temperature observed during trials using fish fillet was 222°C. It can be seen that temperatures reached in these studies exceeded 205°C.

Schroeder (1989) carried out a migration study on migration in susceptors using the method proposed by the FDA for identifying non-volatile migrating species from microwaveable containers laminated with a food contact liner of polyethylene terephthalate. Using a 700 W oven, the susceptor material was exposed for 5 minutes to microwave radiation at full power. The highest temperature recorded was 250°C, suggesting that that location was a hot spot in the microwave oven. The average temperature across the susceptor material was about 232°C. The major compound present as a result of the degradation of the PET layer was cyclic trimer, with a concentration of 12330 mg/dm<sup>2</sup>. Other compounds found were BHET (38.64 mg/dm<sup>2</sup>), DET (334.0 mg/dm<sup>2</sup>), and several oligomers of PET: tetramer, pentamer, hexamer, heptamer, octamer, and nonamer. The concentration of the oligomers obtained at the same exposure time were 0.29, 0.22, 0.16, 0.09, and 0.02 mg/dm<sup>2</sup>, respectively.

## **CHAPTER 3**

### **MATERIALS AND METHOD**

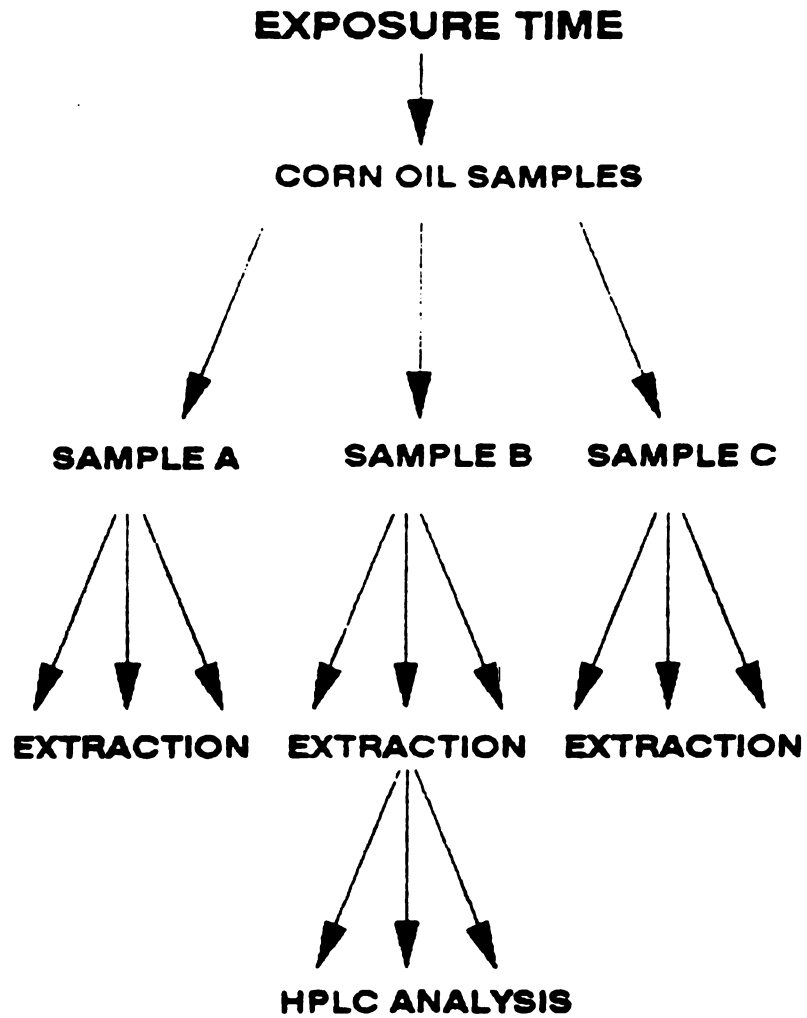
#### **3.1 Introduction**

The analysis used in this study follows the method proposed by the FDA (Schroeder, 1989) for non-volatile extractables in corn oil heated in microwave containers that are laminated with a food contact liner of polyethylene terephthalate (PET) polyester. This method is also being considered for adoption as a standard method by the American Society for Testing and Materials (ASTM) (Schroeder, 1989).

#### **3.2 Experimental Design**

Figure 8 shows the experimental design used in this study. Two packaging systems were used: a susceptor material and crystalized polyethylene terephthalate (CPET). Temperatures at the interface of the food simulant, and test material were monitored with a four-probe Luxtron fluoroptic system (Luxtron Corp., Mountain View, CA) over residence times ranging from 1 to 7 minutes. Corn oil was used as the food simulant and glass beads were used to simulate inert food particles.

Three runs were carried out at each exposure time, using a fresh sample for each run. The temperatures recorded by the four probes in each run were average to obtain the overall temperature profile of the sample at the interface of the test material in that run.



**Figure 8. Experimental Design**

The three average temperature profiles were again averaged to give the final temperature profile of each sample for each exposure time.

Three extractions were done on each corn oil trial and three runs of HPLC done on each extraction. All the area responses obtained from the corn oil samples for each extraction were averaged, and the averaged value was used to calculate the concentration of the migrant.

### **3.3 Samples and Materials**

Both test materials were provided by leading manufacturers. The CPET material came in preformed trays measuring 12 cm x 12 cm x 3 cm. The susceptor material came in flat sheets, and were cut into discs of 13.5 cm diameter to be used in a specially designed migration cell (Figure 9). This procedure allows for a constant surface area of contact and constant simulant volume. The migration cell consists of a Teflon cylinder and a round Teflon base. Teflon was chosen because it can withstand temperatures of up to 260°C without adverse effects on its structure. The cylinder is open at both ends, with a wall thickness of 2.0 cm and a diameter of 12.0 cm. The base is also 2.0 cm thick with a diameter of 19.0 cm. One end of the cylinder can be secured to the base by nylon screws drilled through the wall of the cylinder. A fully assembled cell would have the packaging material sitting on top of a silicone gasket on the Teflon base, secured to the upper cylinder on top of the packaging material so that a constant exposure area is obtained. This also prevents any edge effects, i.e. migration of components from the cut edge of the packaging material into the food simulant. All the materials used in constructing the migration cell were obtained from McMaster, Inc., Chicago, Ill.

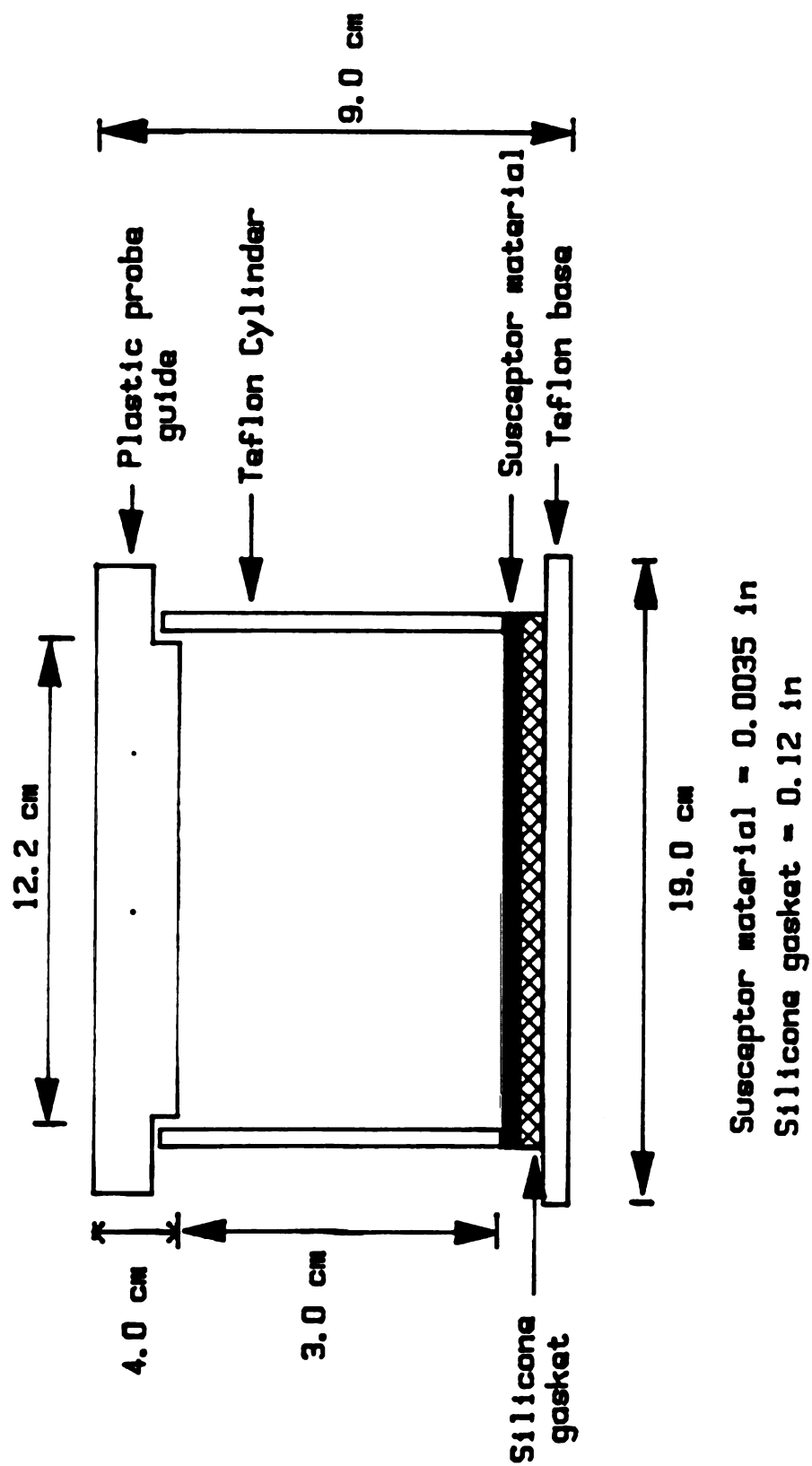


Figure 9. Migration cell for susceptor material  
(not to scale)



Polyethylene terephthalate cyclic trimer, diethyl terephthalate (DET), dimethyl terephthalate (DMT), and bis-(2-hydroxyethyl) terephthalate (BHET) standards were used to identify specific migrants. PET cyclic trimer, DET, and DMT were obtained from the Eastman Kodak Co., Rochester, N.Y.. BHET was obtained from the Research Laboratories, Tennessee Eastman Company. Dimethylacetamide (DMAC) was obtained from the Eastman Kodak Co., Rochester, N.Y. All solvents used were HPLC grade and were obtained from Aldrich Chemical Co., Milwaukee, Wisconsin.

The corn oil (Mazola 100% Pure Corn Oil, Best Foods, CPC International, Inc., Englewood Cliffs, N.J.) was purchased from a local supermarket and refrigerated before each use. It was allowed to equilibrate at room temperature before it was used in the experiments. The glass beads were cleaned thoroughly with acetonitrile and dried in air before use.

### **3.4 Verification of Materials Used**

The food contact surface of the test materials were verified using a Perkin-Elmer 1330 Infrared Spectrophotometer. The attenuated total reflectance (ATR) apparatus was used instead of the direct transmission method because of the thickness and opaqueness of the materials. The infrared spectra of the test materials were then compared to the spectrum of a polyethylene terephthalate polymer run on the same apparatus.

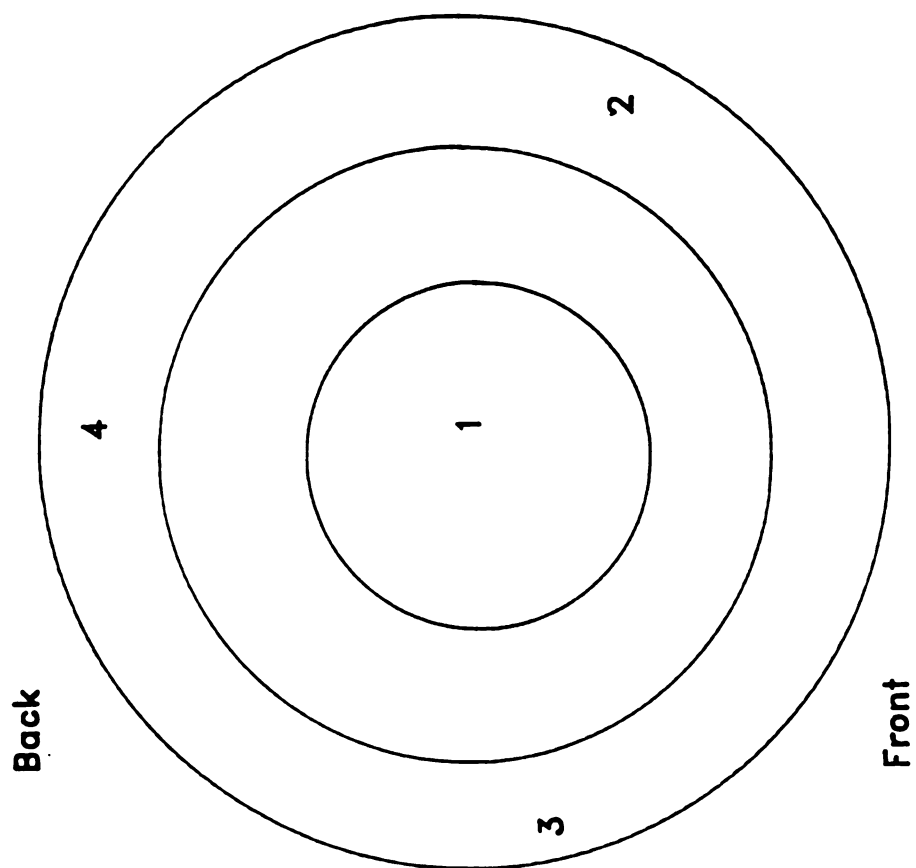
### **3.5 Microwave Exposure**

Glass beads (57.2 g) were placed in the fully assembled cell (susceptor material) or CPET tray so that they formed a single layer on the test material ( $0.5 \text{ g/cm}^2$ ). 17.2 g of corn oil was poured into the cell, and 13.5 g into the tray, so as to maintain a ratio of 0.15 g of corn oil to one  $\text{cm}^2$  of sample surface.

The cell (or tray) was placed in a Litton 500 Watt (2450 MHz) microwave oven (Litton Systems, Inc., Minneapolis, MN) with a cavity measuring 36 cm x 30 cm x 19 cm. The cell (or tray) was placed at exactly the same location in the oven for every run so as to maintain consistency across all trials.

The temperature of the corn oil at the interface of the test materials was simultaneously recorded at four preset locations by Luxtron probes (Luxtron Corp., Mountain View, CA) (Figure 10). For the susceptor material, the temperatures were recorded at intervals of 2 seconds. For the CPET tray, the temperatures were recorded at 4 second intervals. The temperature data were transferred to a computer via a RS 232 serial port. The setup is illustrated in Figure 11. Temperature probes were inserted through pre-drilled holes at the back of the oven, through a plastic probe guide, and the guide aligned so that it was in the same position for each run.

The oil was exposed to microwave energy at full power for residence times of 1 to 7 minutes. A 600 ml glass beaker containing 90 ml of distilled water at room temperature was placed at the back of the oven before each microwave exposure to simulate a food load. The oven cavity was then allowed to cool to room temperature before the next run was made.



**Figure 10.** Preset locations in the plastic probe guide where interface temperatures were recorded for all runs

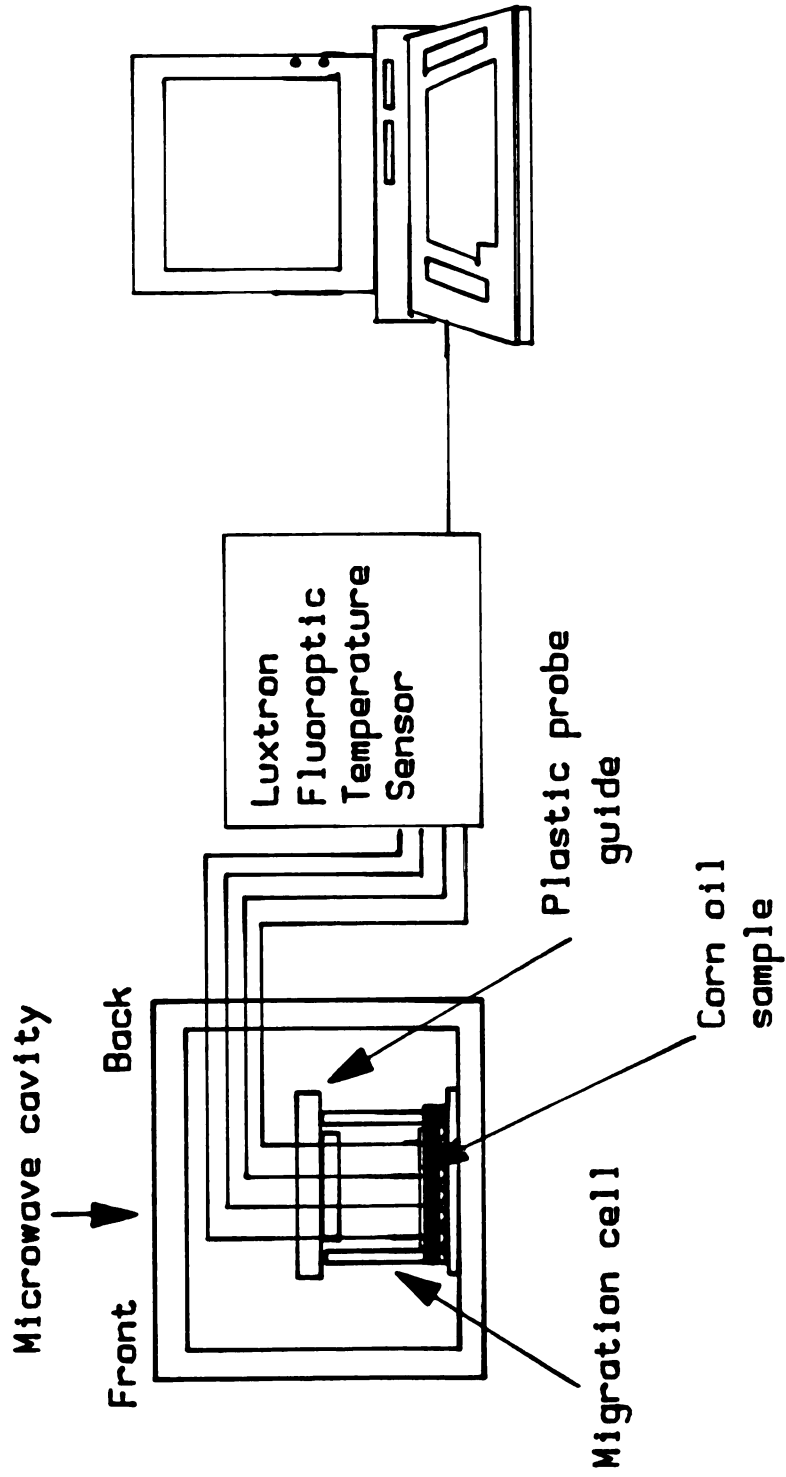


Figure 11. Set-up of experimental apparatus  
(adapted from Komolprasert and Ofoli, 1989)

To determine corn oil blank properties, the same amount of corn oil and glass beads were put in a petri dish. Each packaging material was placed under the petri dish and the dish microwaved as above.

### **3.6 Extraction Procedure**

The hot oil was stirred before taking a  $3.00 \pm 0.003$  g portion for analysis. The oil was mixed with 25 ml hexane, stirred and transferred to a 250 ml separatory funnel. The beaker was rinsed with 25 ml of fresh hexane and added to the first hexane-corn oil mixture. The beaker was then rinsed with 25 ml acetonitrile, stirred, and added to the hexane mixtures. The funnel was shaken and the layers were allowed to separate. The acetonitrile layer was drawn into a 50 ml conical test-tube and the procedure was repeated with 25 ml of fresh acetonitrile. The extracts were combined and evaporated to 0.4 to 0.5 ml under a gentle stream of nitrogen gas during heating at 65°C in a temperature-controlled water bath. The residue was cooled and brought up to 2 ml with dimethylacetamide (DMAC) prior to analysis by liquid chromatography.

### **3.7 High Pressure Liquid Chromatography (HPLC) Analysis**

Each concentrate was injected into a high performance liquid chromatography system using gradient elution. The compounds were quantitatively analyzed using a Perkin-Elmer Model Series 3B liquid chromatography system (Perkin-Elmer, Inc., Norwalk, CT) equipped with a 20  $\mu$ L loop injection valve, a pump capable of 1.5 ml/min, and an LC-100 oven. A Rainin Microsorb C-8 (250 mm x 4.6 mm, 5  $\mu$ m size) (Brown

Laboratories, Santa Clara, CA) column was used with two mobile phases: mobile phase A was 85:15:0.25 water:acetonitrile:glacial acetic acid and mobile phase B was 15:85:0.25 water:acetonitrile:glacial acetic acid.

A linear gradient program was set up to go from 5 to 60% B in 8 minutes, to 70% B in 9 min., to 100% B in 7 min and hold at 100% B for 16 min. at a flow rate of 1.0 ml/min. The eluant was detected using a Perkin-Elmer LC-75 UV Spectrophotometer set at 254 nm. A SP 4200 integrator (Spectra-Physics, Inc., San Jose, CA) with chart speed of 1 in/min was used for the integration of the peaks.

### **3.8 Preparation of Calibration Curves**

An external standard was used to quantitate the major components eluting from the liquid chromatography system. Standard solutions of 100, 50, 10, and 5 ppm were prepared by dissolving each standard in DMAC. Each standard was injected into the liquid chromatography system, under the same conditions used for the analysis of test samples.

A calibration curve was constructed by plotting the response area of each standard versus concentration.

## **CHAPTER 4**

### **RESULTS AND DISCUSSIONS**

#### **4.1 Material Verification**

The infra-red spectrum of polyethylene terephthalate is shown in Figure 12. The spectra of the food contact surface of the susceptor material and CPET tray are shown in Figures 13 and 14, respectively. The infra-red spectra of the food contact surface of the susceptor material and the CPET tray show absorption bands identical to those present in the infra-red spectrum of the polyethylene terephthalate polymer, verifying that the food contact surface of the two test materials is polyethylene terephthalate.

#### **4.2 Microwave Exposure**

##### **4.2.1 Exposure Time versus Temperature**

The highest temperatures attained by the corn oil at the interface of the susceptor material ranged from 136.4°C at 1 minute to 244.8°C at 7 minutes. In the CPET tray, the highest temperatures attained ranged from 34.1°C to 81.9°C for the same length of exposure. The highest temperatures attained in both materials at the end of each heating time are summarized in Table 2.

It was difficult to obtain uniform temperatures during each trial in the range of exposure times used. Temperatures varied slightly across trials, even though each probe

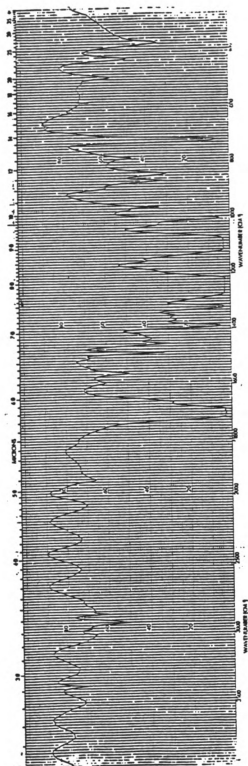


Figure 12. Infra-red spectrum of Polyethylene Terephthalate polymer.



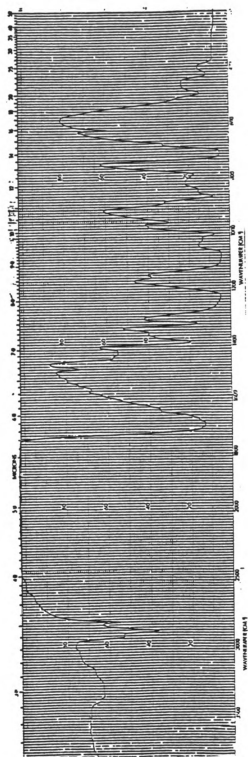


Figure 13. Infra-red spectrum of the food contact layer of the susceptor material.

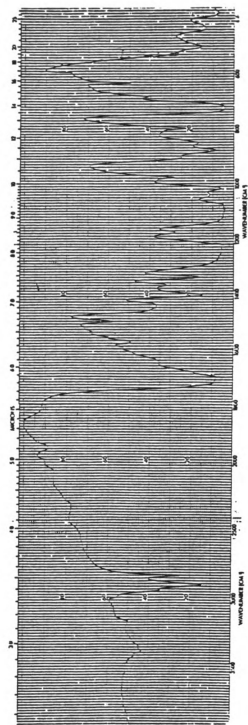


Figure 14. Infra-red spectrum of the food contact layer of the CPET tray.

**Table 2. Highest temperatures attained by the corn oil in the susceptor material and CPET tray during microwave exposure for 1 to 7 minutes.**

| Exposure Time, s | Temperature, °C    |             |
|------------------|--------------------|-------------|
|                  | Susceptor Material | CPET Tray   |
| 60               | 136.4 (6.1)*       | 34.1 (3.9)* |
| 120              | 186.0 (3.4)*       | 45.8 (0.7)* |
| 180              | 196.6 (3.4)*       | 59.9 (3.9)* |
| 240              | 205.4 (1.8)*       | 73.6 (8.0)* |
| 300              | 217.8 (6.6)*       | 78.9 (9.7)* |
| 360              | 225.0 (6.3)*       | 75.6 (3.0)* |
| 420              | 244.8 (7.0)*       | 81.9 (3.7)* |

\* Standard deviation

was located at the same spot in the microwave. It is possible that during trials, convection currents created in the oil at higher temperatures either caused the probes to move away from their original positions or raised them slightly from the interface of the oil and test material. This effect is clearly demonstrated in the temperature profile of corn oil heated in the CPET tray for 6 minutes. The temperature of the corn oil at the interface of the CPET tray was lower at 6 minutes than at 5 minutes of exposure (75.6°C versus 78.9°C) (see Table 2).

This fluctuation could also be due to several other factors (Berek and Wickersheim, 1988): 1) localized heating or localized power absorption instead of gradual equilibration as in a conventional oven; 2) spatial field intensity variations within the oven; 3) dielectric heating which is influenced by localized moisture content in the food; 4) depth of penetration of microwave radiation or 5) handling error.

As expected, the temperature of the corn oil at the interface of the susceptor material was much higher than at the interface of the CPET tray. This is a result of differences in the mode of heating of the two test materials in a microwave oven: absorption of microwave energy by the susceptor material versus transparency of the CPET to microwave radiation as discussed in Chapter 2. Since the aluminum droplets absorb microwave energy, the oil at the interface of the susceptor material gets heated more quickly. The CPET tray, being transparent, does not absorb microwave energy, resulting in lower corn oil temperatures at the interface of the CPET tray. As the CPET tray itself does not absorb microwave energy, heating depends only on the presence of microwave absorbers (water, dipolar ions, etc.) in the oil. Since the quantity of these absorbers in the oil is small, only a modest rise in temperature occurred in the corn oil heated in the CPET tray.

The temperature data from all experiments are tabulated in Appendix A. Based on the temperatures recorded by the four probes at specific locations across the exposed surface area of the test materials, spot or localized heating was prevalent. As exposure time increased, there was considerable locational variation in temperature between the probes. To illustrate this, the temperature profiles at four interface locations after 1 minute of heating was plotted against exposure time (Figure 15). Please see Appendix B for raw data. The initial temperatures measured by probes 1, 2, 3, and 4 were 23.9°C, 23.0°C, 23.5°C, and 23.5 °C, respectively. The average initial temperature was 23.4 °C, with a standard deviation of  $\pm 0.2$  °C. After 60 minutes, the temperature recorded by the respective probes were 115.2°C, 135.8°C, 145.6°C, and 148.4°C. The average temperature was 134.2°C, with a high standard deviation of  $\pm 33.3$ °C.

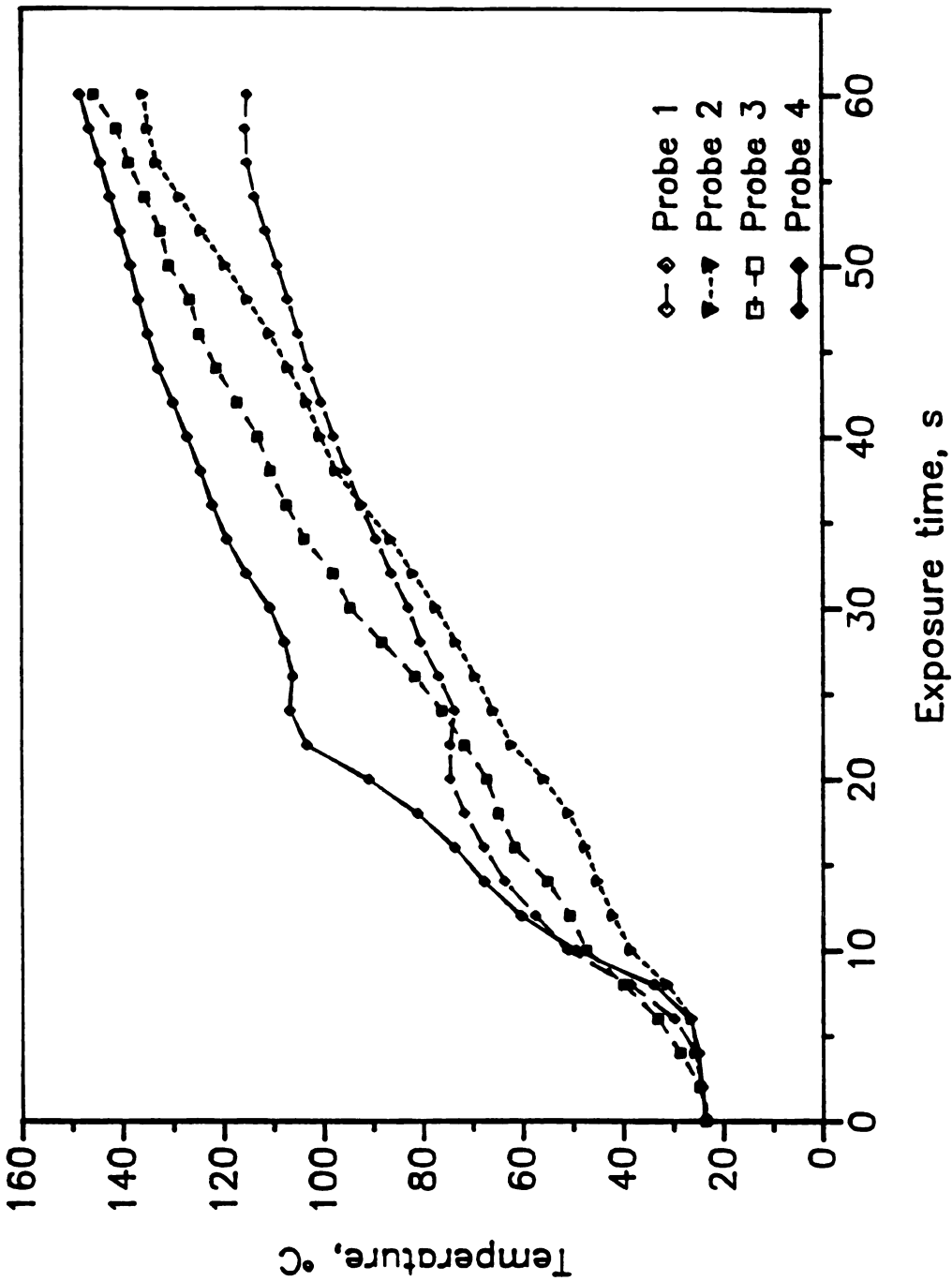


Figure 15. Oil temperature profiles at four interface locations in a  
susceptor after 1 minute of exposure.

Although the variations in temperature between the four probes in each trial were large, the average temperature of all trials was not significantly different, as shown by the standard deviations in Table 2. The smallest temperature variation between trials in the susceptor material was at 4 minutes with a standard deviation of 1.8°C. The largest was at 7 minutes, with a standard deviation of 7.0°C. The range of temperature variation between the trials in the CPET tray was slightly broader than in the susceptor material. The smallest variation was at 2 minutes, with a standard deviation of 0.7°C and the largest was at 5 minutes, with a standard deviation of 9.7°C.

Figures 16 and 17 are plots of the temperature profiles of the corn oil at the interface of the susceptor material and CPET tray, respectively, after exposure times of 2 through 7 minutes. From these plots, it is clear that in spite of the large temperature variations encountered at the different locations of the test materials, there is a great deal of reproducibility in the shape of the average temperature profiles. The profiles from the susceptor material showed that the temperatures at the interface of the oil and material tended towards an asymptote with increased exposure time. In addition, the susceptor material showed better profile reproducibility between exposure times than the CPET tray. This is indicated by the closeness of the seven temperature profiles.

The rate of temperature increase of the corn oil is three to four times greater in the susceptor material than in the CPET tray for the same degree of exposure. For example, at 1 minute, the temperature of corn oil at the interface of the susceptor material was 136.4°C, while that of the CPET was only 34.1°C; these represent increases of 113°C and 13°C, respectively (Figure 18). After 7 minutes, the temperature of the susceptor material had reached 244.8°C, while the temperature of the CPET tray had only reached 81.9°C, a 222.0°C change as compared to a 59°C change in temperature (Figure 19). In Figure 19,

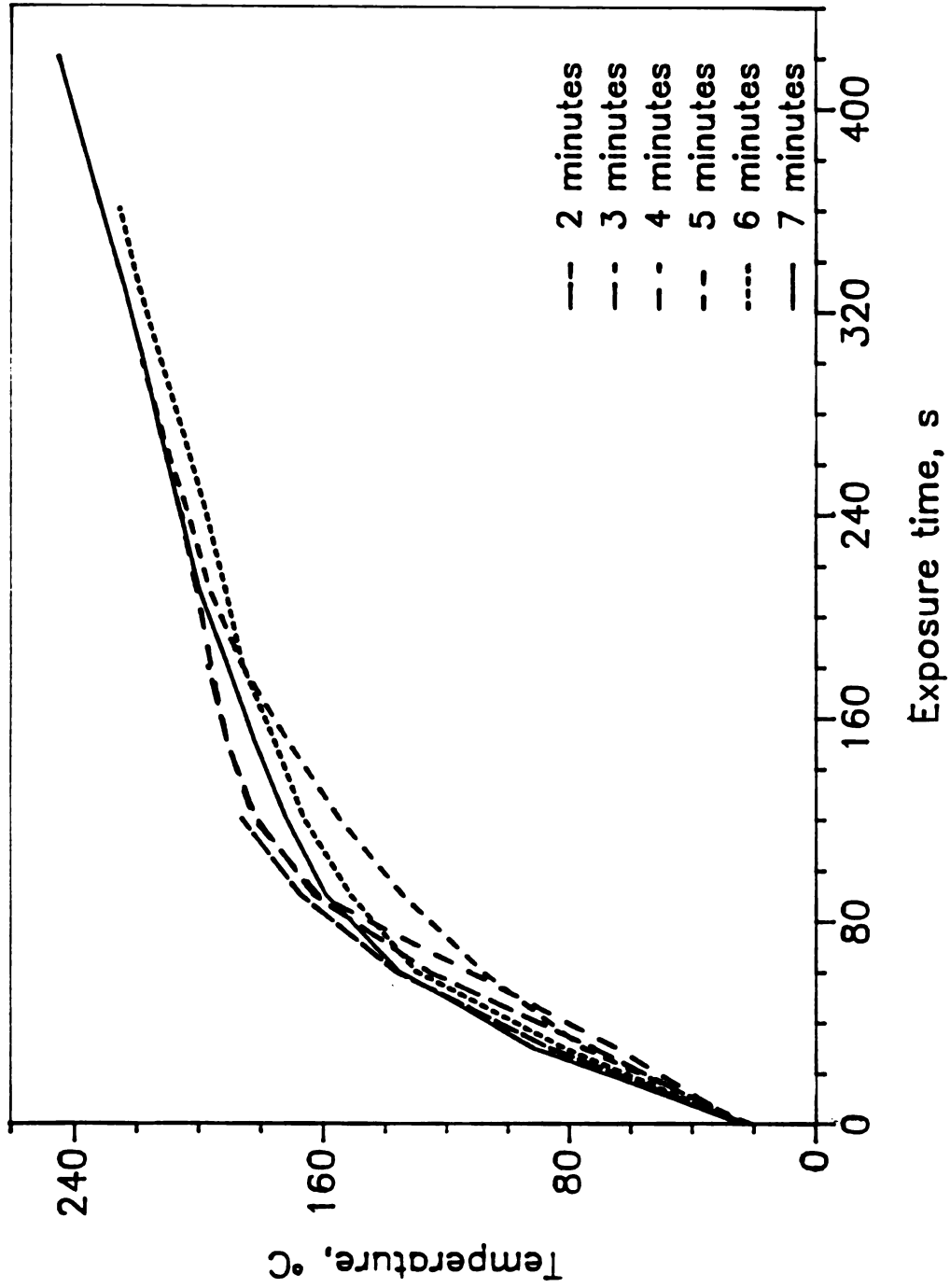


Figure 16. Temperature profiles of corn oil at the interface of the susceptor material for 2 to 7 minutes exposure.

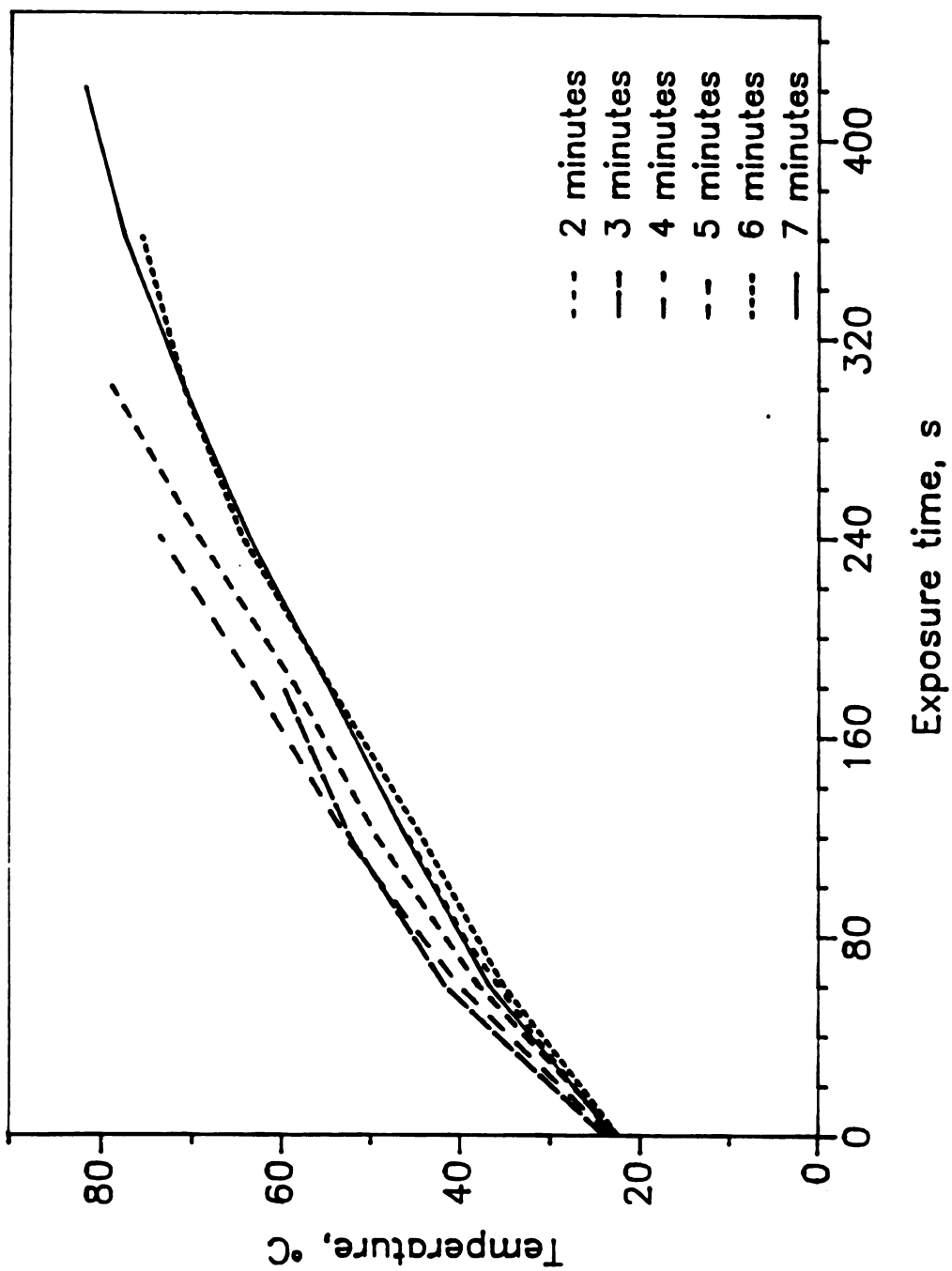


Figure 17. Temperature profiles of corn oil at the interface of the CPET tray for 2 to 7 minutes exposure.



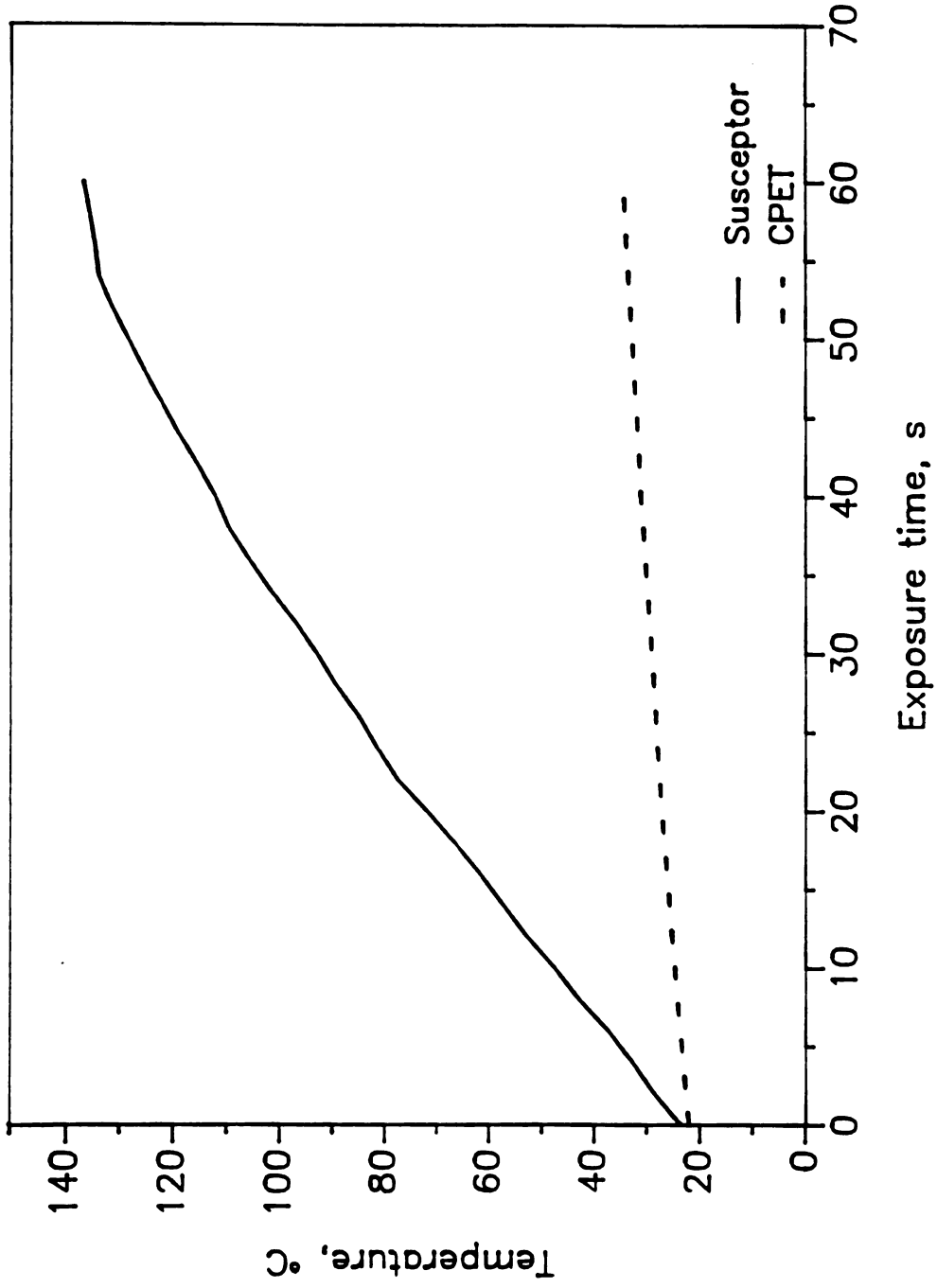


Figure 18. Temperature profiles of corn oil microwaved for 1 minute in a susceptor material and in a CPET tray.

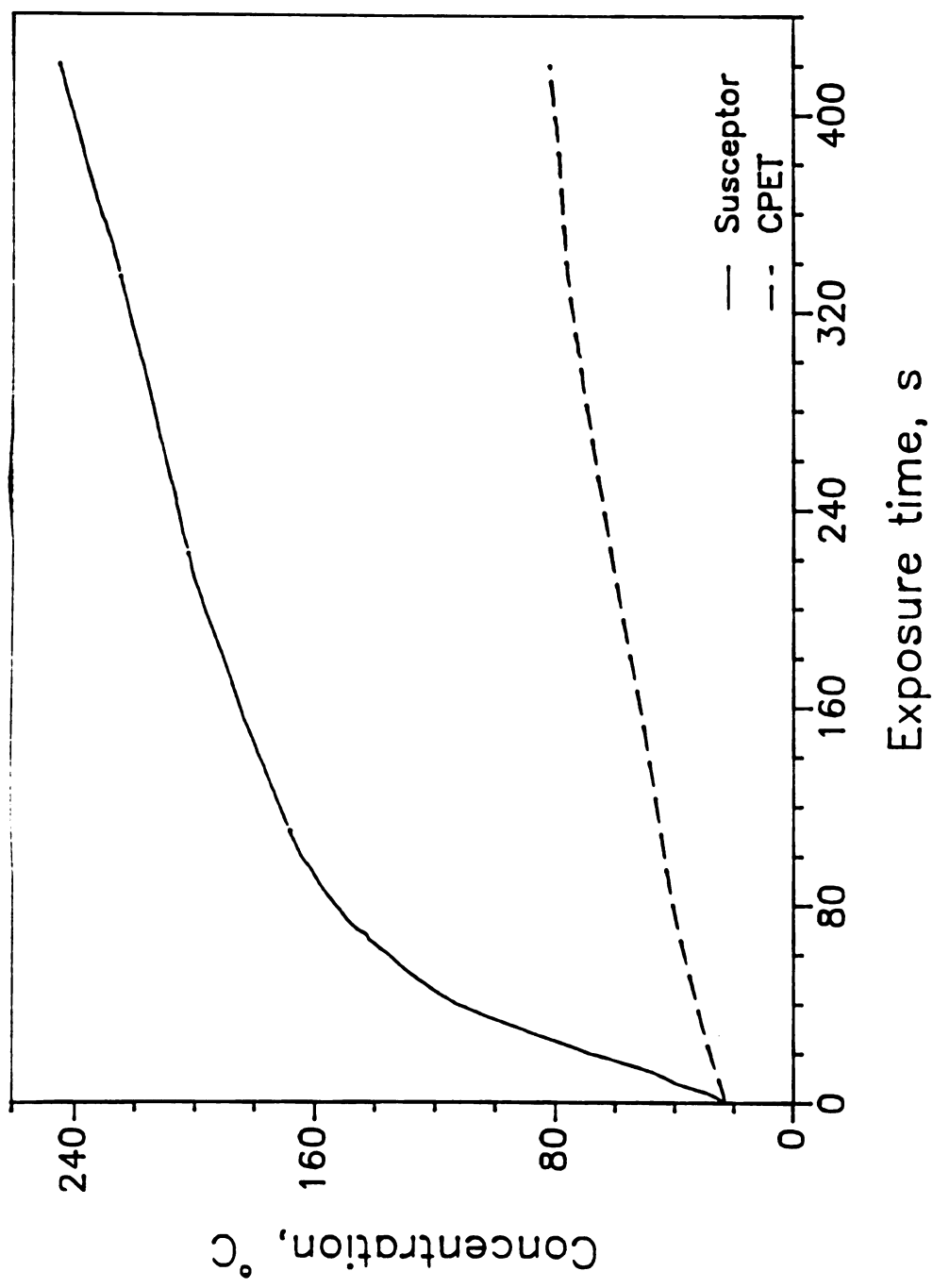


Figure 19. Temperature profiles of corn oil microwaved for 7 minutes in a susceptor material and in a CPET tray.

the temperature profile of the susceptor material showed a sharp increase up to about 1 minute of exposure. After 1 minute, the change in temperature is more gradual and the profile appears to be approaching an asymptote. In contrast, the temperature of corn oil at the interface of the CPET tray is linear with time, even after 7 minutes of exposure.

#### **4.2.2 Effect of Temperature on Susceptor Material**

There were no noticeable changes or breakdown in the structure of the CPET tray during the range of exposure times used, due primarily to the relatively low temperature the material was subjected to. However, significant browning of the susceptor material was observed (Figure 20). A slight browning was observed after 2 minutes of exposure and increased with increased exposure time. After 6 and 7 minutes of exposure, the whole surface of the susceptor was browned, and charring was visible on some parts. It is possible that the position of the parts that were charred coincides with the hot spots in the microwave oven.

After about four minutes of exposure, oil stains were also noticeable on the paperboard layer of the susceptor material. This indicates that some form of structural breakdown (melting, cracking, and/or crazing) of the polyester layer had occurred; no oil stains were observed for exposure times between 1 and 3 minutes.

This breakdown is probably related to the temperature at the interface of the susceptor material. The highest temperature attained by the corn oil at the interface of the susceptor material after 4 minutes was 205.4°C. The heat tolerance range of polyethylene terephthalate, as discussed in Chapter 1, is between 177 and 205°C. Therefore, after four minutes of exposure, the temperature of the corn oil at the interface of the susceptor

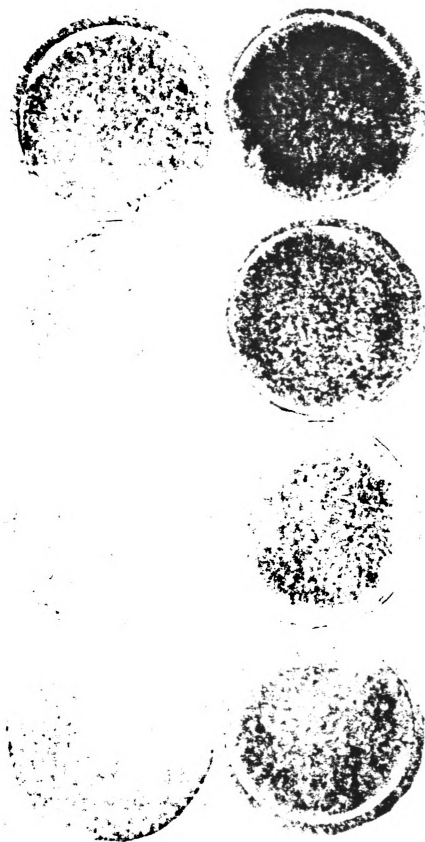


Figure 20. Photograph showing the gradual browning of the susceptible material.  
L to R: Top - 0 microwave, 1 minute, 2 minutes, 3 minutes, 4 minutes  
Bottom - 5 minutes, 6 minutes, 7 minutes, 8 minutes

material had already reached the maximum temperature tolerance of the polyester layer. Actually, it is likely that the actual temperature at the polyester surface of the susceptor material is higher than 205.4°C, exceeding the heat tolerance level of the polyester layer.

The breakdown of the polyester layer allowed the oil to seep through, and come into contact with the paperboard layer below. This accounts for the presence of oil stains on the paperboard layer. The size of the oil stain on the paperboard layer increased with exposure time. After 6 and 7 minutes, it was estimated that 90% of the exposed surface area of the paperboard was covered with oil.

### **4.3 Analysis of migrants by HPLC.**

#### **4.3.1 Standard Curves**

The retention time for BHET, DMT, DET, and Cyclic Trimer standards were 10.0 ( $\pm 0.4$ ), 17.4 ( $\pm 0.3$ ), 22.1 ( $\pm 0.4$ ), 25.7 ( $\pm 0.4$ ) minutes, respectively. Since the method is a reversed phase chromatography, the more polar compounds with respect to the mobile phase elute first, followed by the next less polar compound, ending with the least polar compound. The area response of the standards obtained from the HPLC chromatogram at each concentration is tabulated in Table 3.

The standard curve was plotted using the area response versus the weight of standards injected (Figure 21). The correlation coefficients for the standards were all very good: 1.000 for BHET, 0.999 for DMT, 0.999 for DET and 0.997 for Cyclic Trimer.

To identify the unknown peaks from each corn oil sample, the retention time of the peaks present in the corn oil sample were compared to the retention times of the peaks of the known standards. Since the conditions of the liquid chromatography used is the same for both standards and samples, it is assumed that if the compound of interest (BHET,

**Table 3. Area response of BHET, DMT, DET, and Cyclic Trimer standards at different concentrations.**

| Standard,<br>g ( $\times 10^{-7}$ ) | Area Response, (ARU)* |        |        |               |
|-------------------------------------|-----------------------|--------|--------|---------------|
|                                     | DMT                   | DET    | BHET   | Cyclic Trimer |
| 5                                   | 10790                 | 9200   | 9370   | 9530          |
| 10                                  | 15360                 | 12630  | 14400  | 10670         |
| 50                                  | 73840                 | 53890  | 67960  | 43770         |
| 100                                 | 143000                | 108800 | 135400 | 87500         |

\*Average value of three trials

DET, DMT, Cyclic Trimer) is present in the corn oil sample, it will have the same retention time. A sample chromatogram of the standards at 50 ppm is shown in Figure 22.

#### **4.3.2 Percent Recovery of Standards.**

To determine the percent recovery, corn oil was spiked with known amounts of DMT and DET standards. The corn oil was then extracted and injected into the HPLC following the same procedure used to obtain the standard curves for oil samples heated in the susceptor material and CPET tray. The percent recoveries of the two standards are listed in Table 4.

The percent recoveries for both DET and DMT were very good. They averaged 96.9% and 96.6%, respectively. The percent recovery of the three trials yielded values

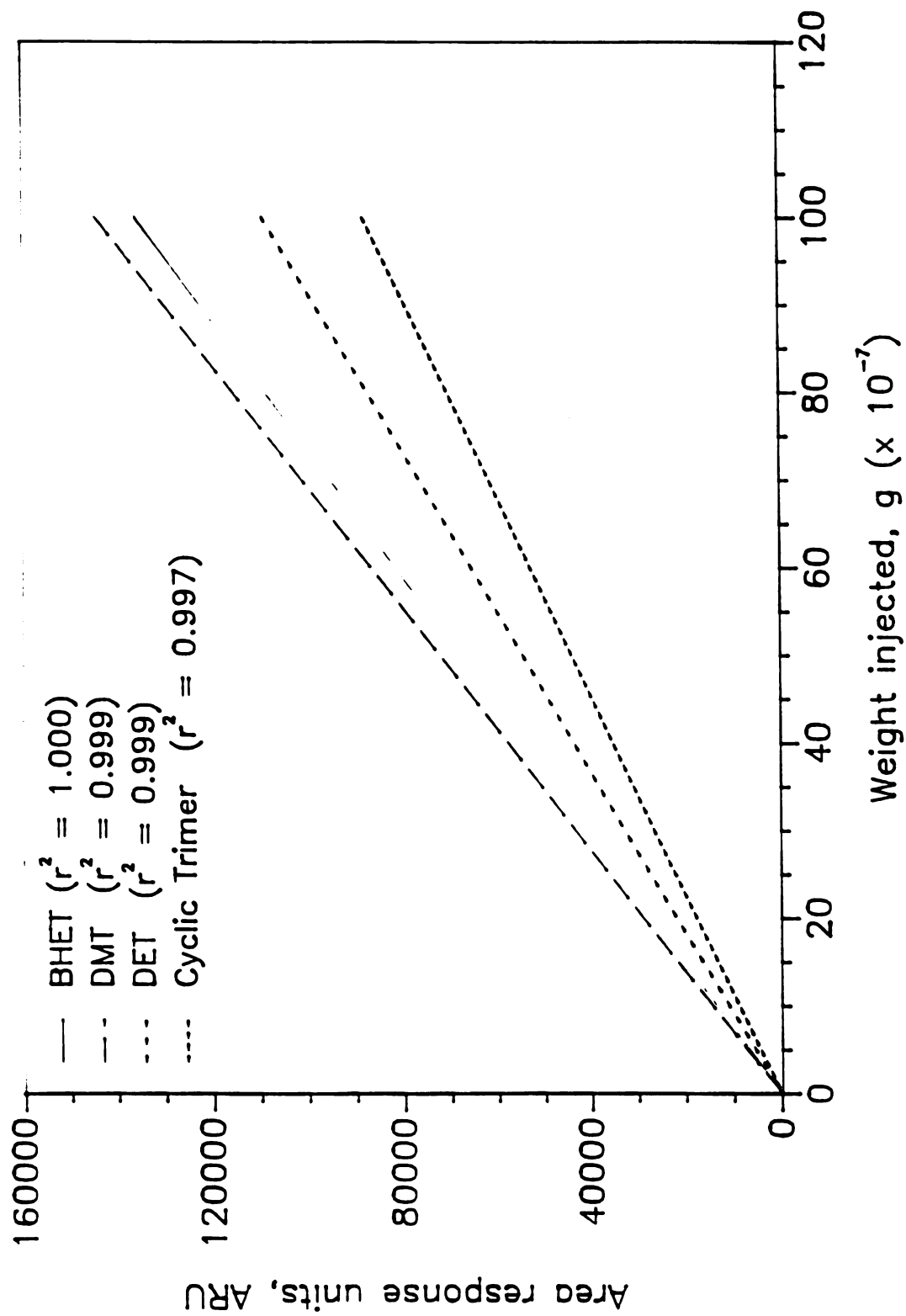


Figure 21. Standard curves for BHET, DMT, DET, and Cyclic Trimer.

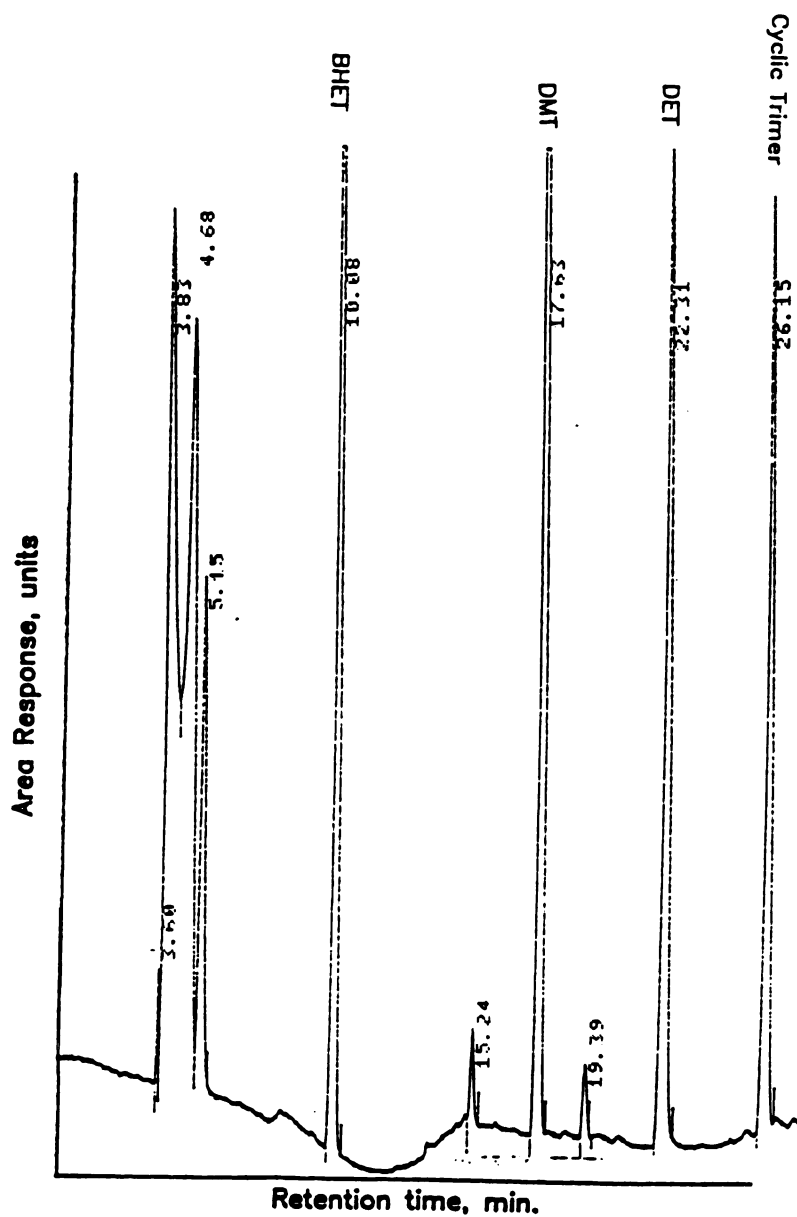


Figure 22. Chromatogram of BHET, DMT, DET, and Cyclic Trimer standards at 50 ppm.



Table 4. Recovery of DMT and DET from corn oil.

| Compound | Added,<br>$\mu\text{g/g}$ | Recovered,<br>$\mu\text{g/g}$ | % Recovery, |
|----------|---------------------------|-------------------------------|-------------|
| DET      | 44.6                      | 43.6                          | 97.7        |
|          | 44.6                      | 43.5                          | 97.6        |
|          | 44.6                      | 42.6                          | 95.5        |
| DMT      | 42.4                      | 42.0                          | 99.4        |
|          | 42.4                      | 42.1                          | 99.1        |
|          | 42.4                      | 38.7                          | 91.3        |

that were very close, with a standard deviation of  $\pm 1.2$  and  $\pm 4.6$  for DET and DMT, respectively. Based on the percent recovery of the two standards, it is reasonable to assume that the compounds of interest present in the corn oil samples would have the same degree of recovery.

### 4.3.3 Sample Analysis

A sample chromatogram of the susceptor material and CPET tray after 7 minutes of exposure are shown in Figures 23 and 24, respectively. Chromatograms for the susceptor material generally had more peaks than chromatograms for the CPET trays. However, when compared to the corn oil blank microwaved at the same exposure time, many of the peaks were found to be identical (Figure 25). Most of the peaks detected in the corn oil blank appear to be breakdown compounds of the corn oil, because a chromatogram of an unmicrowaved corn oil showed no significant peaks (Figure 26). The breakdown is probably thermally induced. The chromatograms of the corn oil

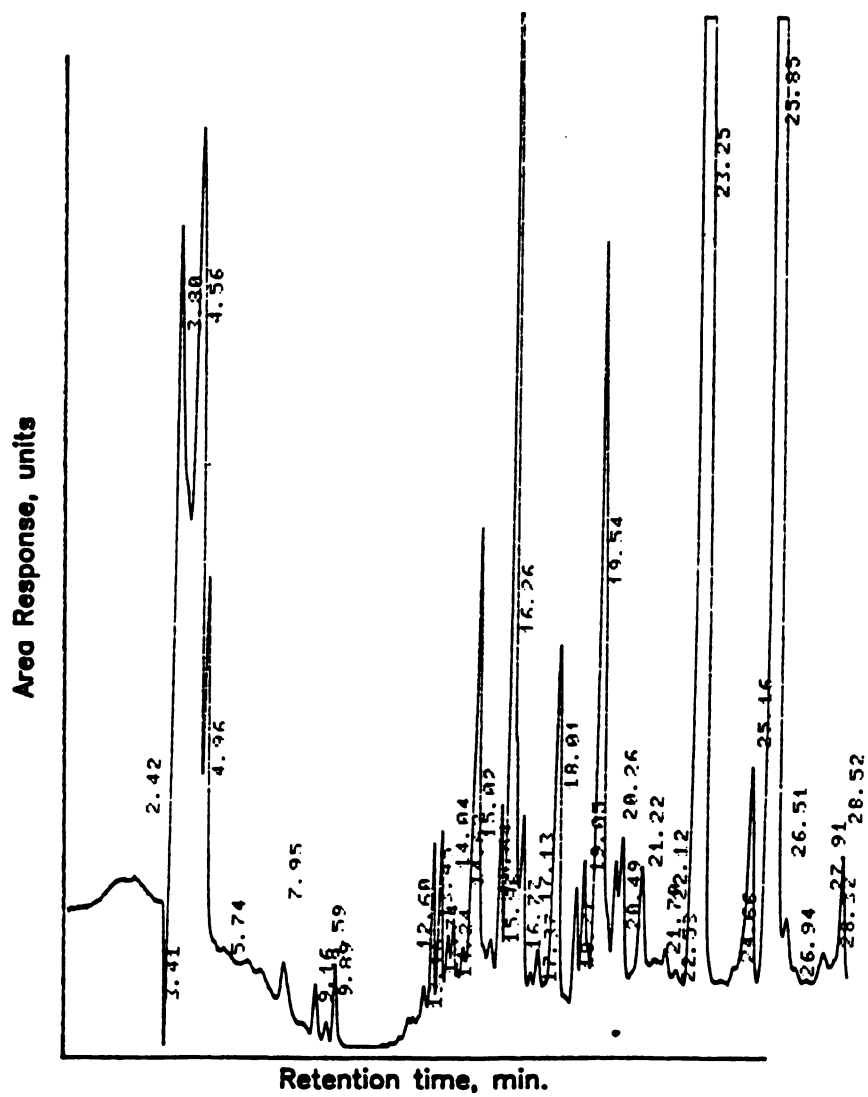


Figure 23. Chromatogram of corn oil extract after 7 minutes exposure in the susceptor material.

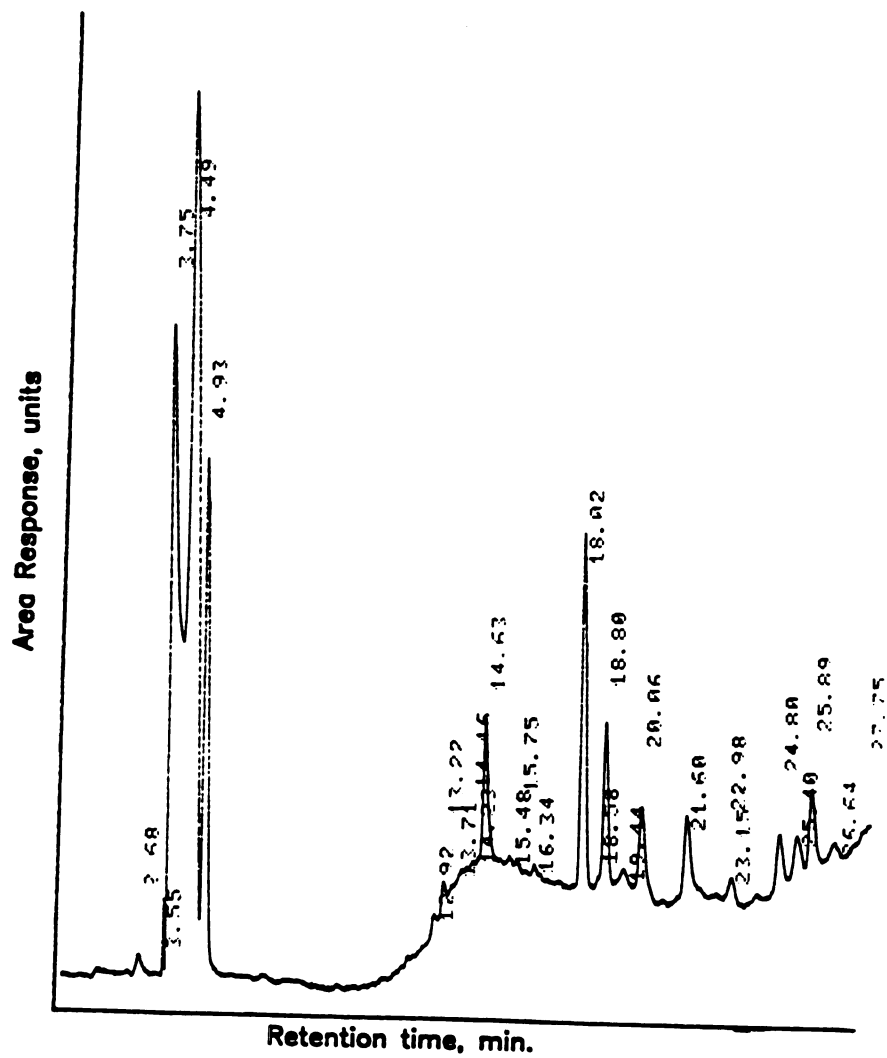


Figure 24. Chromatogram of corn oil extract after 7 minutes exposure in the CPET tray.

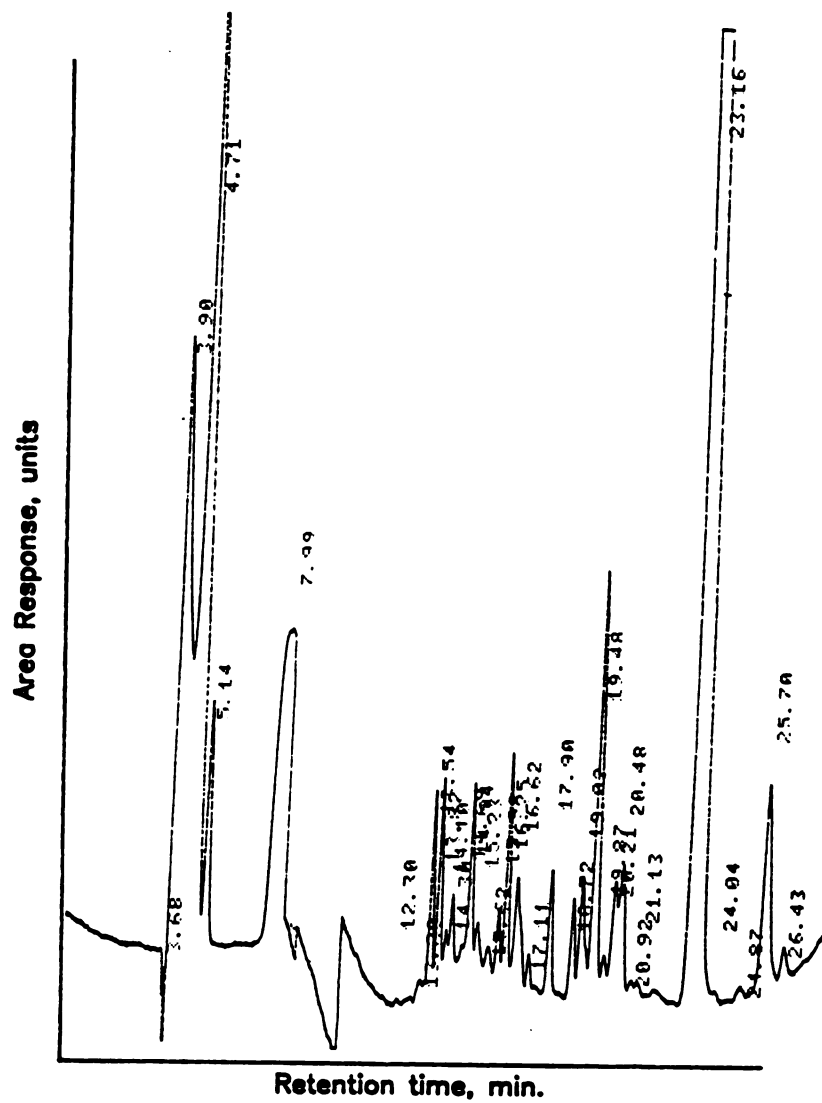


Figure 25. Chromatogram of corn oil blank for the susceptor material after 7 minutes of exposure.

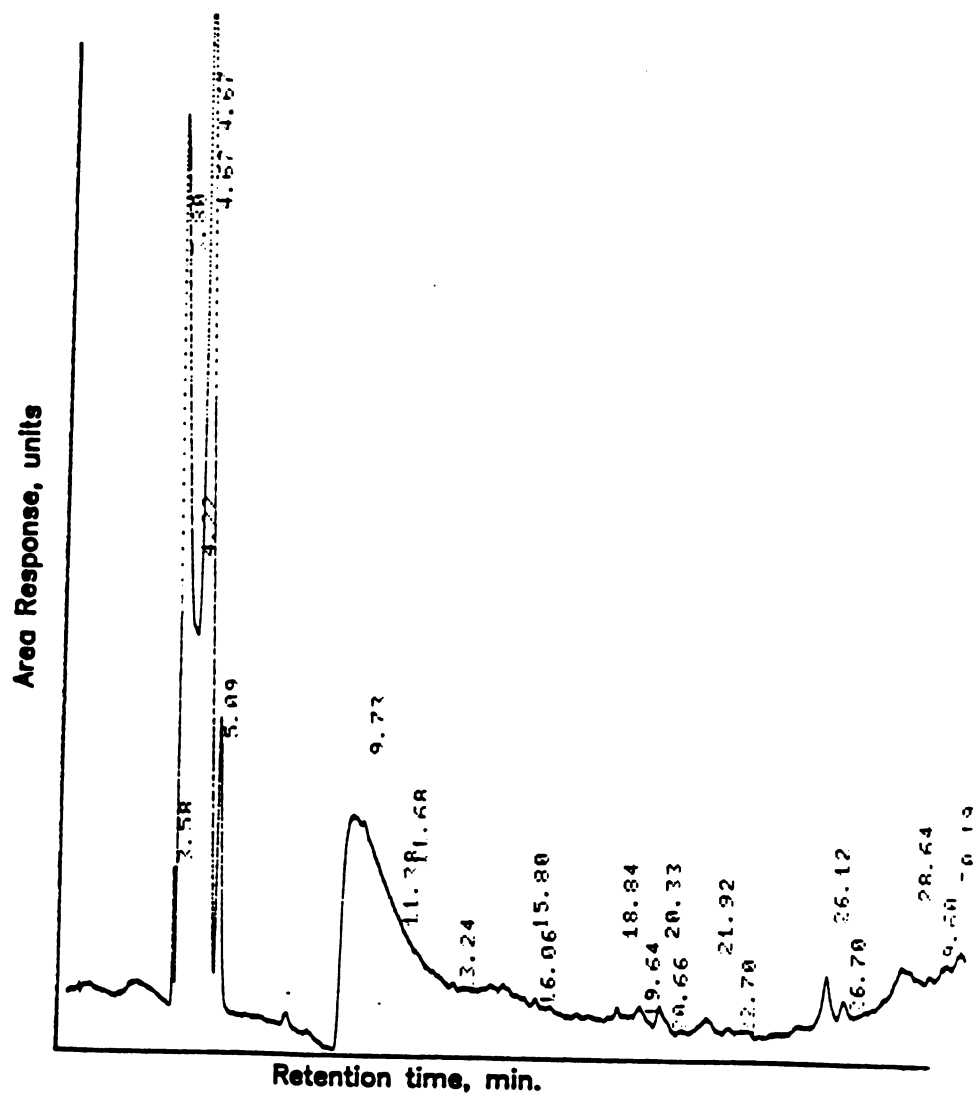


Figure 26. Chromatogram of corn oil blank before microwave exposure.

extract from the susceptor material also showed several large peaks after 29.0 minutes of retention time that were absent in the corn oil blank. These peaks do not coincide with any of the standards used in this study. Therefore, it is possible that the peaks could have come either from the adhesive or the paperboard layer of the susceptor.

To separate the peaks of compounds migrated from the test materials from the breakdown compounds, the peaks of each corn oil blank exposed for the same duration as the sample were subtracted from the chromatograms of the samples. The retention time of the remaining peaks were then compared to the retention time of the known standards to identify peaks with the same retention times as the standards.

All four compounds were present in the chromatograms. DMT and DET are considered residual monomers, BHET is a transesterification product resulting from the processing of polyethylene terephthalate polymer. Cyclic Trimer is inherent in the formation of PET by melt polycondensation, and usually add up to about 1-3% by weight (Kim and Gilbert, 1988). Therefore, it is a natural constituent of all melt-extruded samples of PET.

The BHET peak was easily located. The corn oil blank did not show any compounds with a retention time of between 7.5 minutes and 12.63 minutes. The chromatogram of the corn oil samples showed two compounds that have a retention time close to BHET. One was at about 9.2 minutes and the other at about 9.9 minutes. When compared to the retention time of the BHET standard, the retention time of the second compound was found to be the closest. Thus, that compound was assumed to be BHET.

Peaks for DMT and DET were much harder to detect because of interfering peaks from compounds that were eluting at the same time. Unfortunately, these compounds were also UV absorbers in the 254 nm region of the UV spectrum. As a result, a number

of the peaks were detected by the UV detector. The method of identifying the two peaks involved a process of superimposing the chromatograms obtained from the control and sample and disregarding common peaks: any peaks present in both the corn oil sample and the blank were assumed to be the same compound and eliminated. The retention time of the remaining peaks in the corn oil sample were then compared to the retention times of the DMT and DET standards. The retention times of the DMT and DET peaks in the corn oil sample were 17.3 minutes and 22.1 minutes, respectively.

Among the four compounds, the peak for the Cyclic Trimer was the easiest to identify. While the chromatogram of the corn oil blank has two very prominent peaks; one at 19.5 and the other 23.3 minutes, the chromatogram of the corn oil sample has four: at 16.3, 19.5, 23.3, and 25.9 minutes, respectively. From this information, it can be deduced that the peak at retention times 19.5 and 23.3 minutes are breakdown compounds of the corn oil. Between the two remaining peaks, the peak with the retention time of 25.9 minutes agrees closely with the retention time of the Cyclic Trimer standard, which is 25.7 minutes.

#### 4.3.4 Concentration of DMT, DET, BHET and Cyclic Trimer

The concentration of DMT, DET, BHET and Cyclic Trimer in the corn oil samples were calculated by:

$$\text{Concentration } (\mu\text{g}/\text{dm}^2) = \frac{CF \times R_s \times V_{\text{total}}}{V_{\text{inj}} \times A} \quad (5)$$

where CF = calibration factor (the reciprocal of the slope from the standard curve) [grams per area response units (ARU)] (Table 5);  $R_s$  is the area response obtained from the area of the peak in the chromatogram (ARU) (Table 6);  $V_{\text{total}}$  is the total volume of the sample (ml);  $V_{\text{inj}}$  is the volume of the sample injected into the liquid chromatograph (ml); and  $A$  is the surface area of the test material in contact with the oil sample ( $\text{dm}^2$ ). A sample calculation of the concentration of the compounds is given in Appendix C.

Table 5. Calibration factors for DMT, DET, BHET, and Cyclic Trimer standards.

| Compound      | Slope of Standard curve,<br>ARU/g | Calibration factor (1/slope),<br>g/ARU |
|---------------|-----------------------------------|----------------------------------------|
| DMT           | $1.44 \times 10^{10}$             | $6.94 \times 10^{-11}$                 |
| DET           | $1.09 \times 10^{10}$             | $9.17 \times 10^{-11}$                 |
| BHET          | $1.36 \times 10^{10}$             | $7.35 \times 10^{-11}$                 |
| Cyclic Trimer | $8.81 \times 10^9$                | $1.14 \times 10^{-10}$                 |

Table 7 summarizes the concentrations of DMT, DET, BHET, and Cyclic Trimer extracted from the susceptor material at the respective exposure times. The concentration of the compounds increased with increased temperature of corn oil at the interface of the test material. The highest concentration of DMT, DET, BHET, and Cyclic Trimer extracted were  $361.5 \mu\text{g}/\text{dm}^2$ ,  $343.6 \mu\text{g}/\text{dm}^2$ ,  $42.0 \mu\text{g}/\text{dm}^2$ , and  $12330 \mu\text{g}/\text{dm}^2$ , respectively. Figure 27 shows the concentration profiles of the four compounds. The concentration of Cyclic Trimer extracted during the range of exposure times was two orders of magnitude larger than DMT and DET and about three orders of magnitude larger than BHET.



**Table 6. Average area response of DMT, DET, BHET, and Cyclic Trimer from corn oil samples**

| Exposure Time, s | Area Response, ARU* |       |      |               |
|------------------|---------------------|-------|------|---------------|
|                  | DMT                 | DET   | BHET | Cyclic Trimer |
| 60               | 2360                | 1470  | 1080 | 54400         |
| 120              | 17900               | 12200 | 2690 | 561500        |
| 180              | 27500               | 12400 | 2560 | 565700        |
| 240              | 27400               | 15600 | 3340 | 621200        |
| 300              | 24100               | 21300 | 3000 | 632400        |
| 360              | 25400               | 21700 | 3040 | 616000        |
| 420              | 30400               | 21900 | 3200 | 628400        |

\*Average of three trials

**Table 7. Concentration of DMT, DET, BHET, and Cyclic Trimer extracted from susceptor material after exposure times of 1 to 7 minutes.**

| Exposure Time, s | Concentration, $\mu\text{g}/\text{dm}^2$ * |       |      |               |
|------------------|--------------------------------------------|-------|------|---------------|
|                  | DMT                                        | DET   | BHET | Cyclic Trimer |
| 60               | 28.1                                       | 23.2  | 13.6 | 1060          |
| 120              | 212.7                                      | 191.7 | 33.9 | 10950         |
| 180              | 326.6                                      | 194.9 | 32.2 | 11030         |
| 240              | 325.7                                      | 244.8 | 42.0 | 12120         |
| 300              | 286.3                                      | 334.0 | 37.7 | 12330         |
| 360              | 301.1                                      | 340.6 | 38.2 | 12020         |
| 420              | 361.5                                      | 343.6 | 40.2 | 12260         |

\*Average of three trials

The profiles also show that the maximum concentration of each compound was reached within 7 minutes of exposure. BHET does not show significant changes in concentration with respect to exposure time. However, the concentrations of DMT, DET, and Cyclic Trimer changed significantly between 1 and 2 minutes of exposure. The

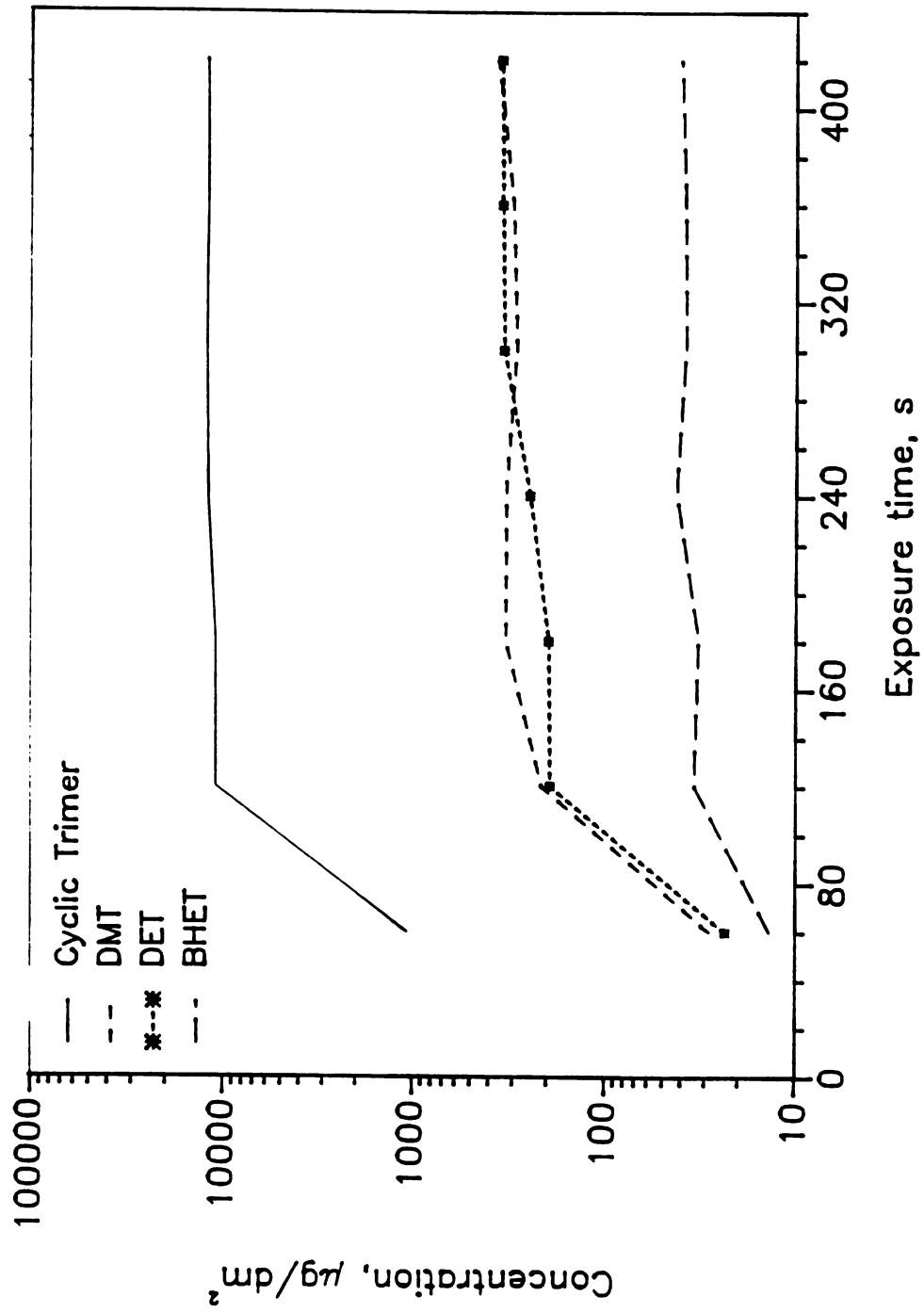


Figure 27. Concentration of Cyclic Trimer, DMT, DET, and BHET extracted from corn oil samples heated in the susceptor material for 1 to 7 minutes.

concentration of DMT and DET increased by a factor of 8, from 28.1  $\mu\text{g}/\text{dm}^2$  to 212.7  $\mu\text{g}/\text{dm}^2$ ) and from 23.2  $\mu\text{g}/\text{dm}^2$  to 191.7  $\mu\text{g}/\text{dm}^2$ ), respectively. The Cyclic Trimer experienced a ten-fold increase, from 1060  $\mu\text{g}/\text{dm}^2$  to 10950  $\mu\text{g}/\text{dm}^2$ ). DET and DMT reached a maximum concentration after 5 and 3 minutes, respectively, while Cyclic Trimer leveled off after only 1 minute of exposure.

The concentrations found in this study were compared to a preliminary work reported by Schroeder (1989), the concentration levels of the migrated compounds in the corn oil were quite different (Table 8).

**Table 8.** Comparison of experimental conditions and concentrations of BHET, DET, and Cyclic Trimer after 5 minutes of exposure.

|                          | Schroeder (1989)                         | This study |
|--------------------------|------------------------------------------|------------|
| Compounds:               | Concentration, $\mu\text{g}/\text{dm}^2$ |            |
| BHET                     | 3.1                                      | 38.6       |
| DET                      | 2914.01                                  | 334        |
| Cyclic Trimer            | 1780                                     | 12300      |
| Experimental conditions: |                                          |            |
| Oil temperature          | 232.0°C                                  | 217.8°C    |
| Power level              | 700 W                                    | 500 W      |

BHET migration was ten times higher while the concentration of Cyclic Trimer was about seven times as much. However, the concentration of DET obtained in this study was about five times smaller than their reported value. These differences can be attributed to a variation in experimental temperature, the type of oven used, and the fact that different susceptor boards were used in the two studies. No comparison could be made on the amount of DMT extracted, since Schroeder (1989) did not report on this compound.

None of the four compounds of interest could be extracted from the CPET tray because of the low temperatures attained by the corn oil. The highest temperature attained by the corn oil at the interface of the CPET tray (81.9°C) was below the glass transition temperature of the PET, which is about 98°C. At this temperature, migrants could remain bound to the crystalline polymer instead of diffusing into the contacting phase.

## **CHAPTER 5**

### **SUMMARY AND CONCLUSIONS**

**There is a marked difference in the rate of heating of oil held in a susceptor material and that held in the CPET tray in the microwave oven. The rate of temperature increase of the corn oil at the interface of the susceptor material was three to four times that of the CPET tray for the same exposure time. Over the exposure times of 1 to 7 minutes, the highest temperatures recorded at the interface of the susceptor material were 136.4°C, 186.0°C, 196.6°C, 205.4°C, 217.8°C, 225.0°C, and 244.8°C, respectively. In contrast, the highest temperatures of the corn oil recorded at the interface of the CPET tray were 34.1°C, 45.8°C, 59.9°C, 73.6°C, 78.9°C, 75.6°C, and 81.9°C, respectively.**

**The result of this study confirmed earlier reports concerning the structural breakdown of the PET barrier layer of susceptor materials during prolonged exposures. Structural breakdown of the susceptor material started after 4 minutes of exposure, at a temperature of about 205.4°C. Extensive structural breakdown occurred after 6 and 7 minutes of exposure, judging by the number of oil stains on the paperboard layer of the susceptor material and the cracking of the polyester layer. It is recommended that foods held in susceptors should not be heated for more than four minutes. This is because, for small loads, the temperature may exceed the ignition temperature of paper. After 7 minutes of exposure, the CPET did not seem to have suffered any apparent breakdown of its structure.**

The structural breakdown of the susceptor material appeared to have reached the adhesive and paperboard layers. According to the Code of Federal Regulations, adhesives can be used if they are separated from the food by a functional barrier or if used in packages that are intended for fatty foods, the amount of adhesive in contact should not exceed the trace amount at seams and edge exposure between packaging laminates (Anon, 1989a). Due to structural breakdown at high temperatures, the polyester layer can no longer provide the required barrier for the adhesive, making it possible for the adhesive to come into contact with the food simulant.

All four compounds of interest (DMT, DET, BHET, and Cyclic Trimer) were found in the extract of the corn oil heated in the susceptor material. Concentrations of DMT, DET, Cyclic Trimer, and BHET increased as the temperature at the interface increased. Maximum concentrations of the four compounds were attained within 7 minutes of exposure. The concentrations of DMT after 1 to 7 minutes of exposure were 28.1, 212.7, 326.6, 325.7, 286.3, 301.1, and 361.5  $\mu\text{g}/\text{dm}^2$ , respectively. The concentrations of DET after 1 to 7 minutes of exposure were 23.2, 191.7, 194.9, 244.8, 334.0, 340.6, 343.6  $\mu\text{g}/\text{dm}^2$ , respectively. Concentrations of BHET after 1 to 7 minutes were 13.6, 33.9, 32.2, 42.0, 37.7, 38.2, and 40.2  $\mu\text{g}/\text{dm}^2$ , respectively. Concentrations of cyclic trimer after 1 to 7 minutes of exposure were 1060, 10950, 11030, 12120, 12330, 12020 and 12260  $\mu\text{g}/\text{dm}^2$ , respectively.

Regulations on the allowable levels of DMT, DET, BHET, and Cyclic Trimer extracted from a polymer at any time-temperature condition are not yet listed under Part 177 (Indirect food additives from polymers) of the FDA's Code of Federal Regulations (Anon, 1989b). Therefore, the quantity of the four migrants extracted in this study could not be compared to any standards.

Corn oil does not appear to be an ideal food simulant. At high temperatures, the chromatogram of the corn oil blank extracts showed numerous peaks, suggesting that the corn oil experienced some form of structural breakdown, especially after 4 minutes of exposure. In addition, the breakdown products absorb at the same wavelength used to detect the samples, making identification of the compounds of interest more difficult.

Regulations on the migration of paperboard additives at high temperature are non-existent. The highest temperature cited in the FDA's Code of Federal Regulations for extractability test conditions for paperboard additives is at 250°F for 2 hours for high temperature heat-sterilized packages (Anon, 1989c). When the extractability test conditions were drafted, they did not expect that paper or paperboard would be subjected to the temperatures that the susceptor material is capable of producing. It is apparent that the temperature to which the paperboard is exposed exceeds the temperature for the extractability test set by the FDA.

The food contact layer of the susceptor material and the CPET tray appears to be polyethylene terephthalate, based on the similarity of the infra-red spectra profiles of the food contact layer of the susceptor and CPET tray to the infra-red spectrum of polyethylene terephthalate polymer.

This study dealt with a model system, rather than a real food system. The results could be an exaggeration of what happens in a real food system, especially with respect to the temperatures attained in the susceptor material. An ideal situation would be to use a formulation to simulate a system that could be encountered in microwaveable foods. As reported by Bieber et al. (1984), migration of low molecular weight substances from plastics, adhesives or paperboard into foodstuffs is influenced by many components and

**properties of the food, including the fat-releasing properties, pH value, and its alcohol content. Therefore, studies comparing real foodstuffs and food simulants to establish a more reasonable picture on the migration phenomena are needed.**



## **CHAPTER 6**

### **SUGGESTIONS FOR FURTHER RESEARCH**

**The following studies are recommended:**

- 1. Identification of a different food simulant (for example a more saturated fat, or an engineered triglyceride) that will not breakdown at high temperatures.**
- 2. A study of the migration of adhesives and paperboard additives from the susceptor material.**
- 3. Identification and characterization of the unidentified peaks that were found in the corn oil extracts of the susceptor material, perhaps by a preparative HPLC procedure.**
- 4. Development of a different method of identification, (infra-red analysis, TLC, mass spectroscopy, etc.) for confirmation of the peaks. This will help overcome the fact that the HPLC method only provides constructive identification.**
- 5. A study of migration in real food systems should be conducted so that a comparison can be made to check on the accuracy of using model systems.**

## CHAPTER 7

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**APPENDIX A1. Average temperature of corn oil heated in susceptor material for one minute.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 23.5            | 23.4    | 23.5    | 23.5    |
| 2.0     | 24.5            | 24.6    | 24.3    | 24.5    |
| 4.0     | 26.7            | 26.9    | 26.2    | 26.6    |
| 6.0     | 29.7            | 28.8    | 29.0    | 29.2    |
| 8.0     | 36.5            | 35.1    | 35.9    | 35.8    |
| 10.0    | 45.6            | 47.1    | 46.6    | 46.4    |
| 12.0    | 50.0            | 55.3    | 52.6    | 52.6    |
| 14.0    | 54.5            | 58.8    | 57.8    | 57.1    |
| 16.0    | 58.9            | 62.9    | 62.6    | 61.5    |
| 18.0    | 63.4            | 68.1    | 67.8    | 66.4    |
| 20.0    | 68.1            | 73.2    | 73.8    | 71.7    |
| 22.0    | 73.1            | 78.1    | 80.7    | 77.3    |
| 24.0    | 75.8            | 84.2    | 83.6    | 81.2    |
| 26.0    | 79.9            | 87.8    | 86.5    | 84.7    |
| 28.0    | 84.5            | 92.6    | 90.4    | 89.1    |
| 30.0    | 87.9            | 96.5    | 93.7    | 92.7    |
| 32.0    | 92.4            | 99.7    | 98.2    | 96.8    |
| 34.0    | 96.5            | 105.4   | 102.2   | 101.4   |
| 36.0    | 101.4           | 108.4   | 106.6   | 105.5   |
| 38.0    | 106.1           | 111.1   | 110.7   | 109.3   |
| 40.0    | 109.2           | 112.4   | 113.7   | 111.8   |
| 42.0    | 112.6           | 115.8   | 117.0   | 115.1   |
| 44.0    | 116.4           | 119.2   | 120.6   | 118.7   |
| 46.0    | 119.5           | 123.0   | 123.4   | 121.9   |
| 48.0    | 122.6           | 126.5   | 126.2   | 125.1   |
| 50.0    | 125.5           | 130.0   | 128.7   | 128.1   |
| 52.0    | 128.4           | 133.5   | 131.4   | 131.1   |
| 54.0    | 130.3           | 137.2   | 133.4   | 133.6   |
| 56.0    | 131.2           | 140.7   | 134.1   | 135.3   |
| 58.0    | 131.9           | 143.2   | 133.7   | 136.3   |
| 60.0    | 133.2           | 143.5   | 132.6   | 136.4   |

**APPENDIX A2. Average temperature of corn oil heated in susceptor material for two minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 22.1            | 22.6    | 23.2    | 22.6    |
| 2.0     | 23.0            | 25.8    | 25.6    | 24.8    |
| 4.0     | 28.2            | 29.0    | 29.6    | 28.9    |
| 6.0     | 37.7            | 32.9    | 31.5    | 34.0    |
| 8.0     | 45.1            | 37.4    | 33.8    | 38.8    |
| 10.0    | 51.3            | 40.4    | 36.8    | 42.8    |
| 12.0    | 56.8            | 43.0    | 40.1    | 46.6    |
| 14.0    | 65.0            | 45.8    | 42.8    | 51.2    |
| 16.0    | 70.8            | 49.1    | 46.2    | 55.4    |
| 18.0    | 76.3            | 52.5    | 49.8    | 59.5    |
| 20.0    | 80.7            | 55.5    | 53.3    | 63.2    |
| 22.0    | 85.1            | 60.5    | 57.1    | 67.6    |
| 24.0    | 90.7            | 65.5    | 61.3    | 72.5    |
| 26.0    | 96.5            | 70.6    | 66.6    | 77.9    |
| 28.0    | 99.5            | 76.1    | 70.7    | 82.1    |
| 30.0    | 103.7           | 80.5    | 74.9    | 86.4    |
| 32.0    | 107.9           | 85.4    | 79.5    | 90.9    |
| 34.0    | 112.2           | 89.6    | 84.0    | 95.3    |
| 36.0    | 116.1           | 93.6    | 88.6    | 99.4    |
| 38.0    | 119.6           | 97.5    | 91.9    | 103.0   |
| 40.0    | 122.7           | 101.5   | 95.9    | 106.7   |
| 42.0    | 125.8           | 105.8   | 99.6    | 110.4   |
| 44.0    | 129.0           | 109.0   | 103.3   | 113.8   |
| 46.0    | 131.9           | 111.8   | 106.6   | 116.8   |
| 48.0    | 134.1           | 114.2   | 110.1   | 119.5   |
| 50.0    | 136.5           | 117.2   | 113.3   | 122.3   |
| 52.0    | 138.8           | 120.0   | 116.6   | 125.1   |
| 54.0    | 140.7           | 123.3   | 119.7   | 127.9   |
| 56.0    | 142.9           | 126.4   | 123.3   | 130.9   |
| 58.0    | 145.3           | 128.8   | 127.1   | 133.7   |
| 60.0    | 146.9           | 131.5   | 130.5   | 136.3   |
| 62.0    | 148.6           | 134.1   | 133.6   | 138.8   |
| 64.0    | 150.1           | 137.1   | 136.3   | 141.2   |
| 66.0    | 151.4           | 139.9   | 139.0   | 143.4   |
| 68.0    | 152.7           | 142.8   | 141.7   | 145.7   |
| 70.0    | 153.9           | 145.4   | 144.0   | 147.8   |
| 72.0    | 155.2           | 147.6   | 146.4   | 149.7   |
| 74.0    | 156.5           | 150.0   | 148.5   | 151.7   |
| 76.0    | 157.7           | 152.3   | 151.0   | 153.7   |
| 78.0    | 158.7           | 154.4   | 153.3   | 155.5   |



**APPENDIX A2 (con't)**

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 80.0  | 159.6 | 156.4 | 155.8 | 157.3 |
| 82.0  | 161.2 | 158.2 | 158.5 | 159.3 |
| 84.0  | 162.6 | 160.4 | 161.3 | 161.4 |
| 86.0  | 164.3 | 162.4 | 164.1 | 163.6 |
| 88.0  | 165.9 | 164.6 | 166.3 | 165.6 |
| 90.0  | 167.0 | 166.0 | 168.4 | 167.1 |
| 92.0  | 168.2 | 167.7 | 170.3 | 168.7 |
| 94.0  | 169.6 | 170.4 | 172.1 | 170.7 |
| 96.0  | 170.5 | 172.9 | 173.7 | 172.4 |
| 98.0  | 171.7 | 174.7 | 175.0 | 173.8 |
| 100.0 | 172.8 | 175.8 | 176.6 | 175.1 |
| 102.0 | 173.9 | 167.2 | 178.0 | 173.0 |
| 104.0 | 174.7 | 178.7 | 179.9 | 177.8 |
| 106.0 | 175.8 | 180.1 | 181.2 | 179.0 |
| 108.0 | 177.0 | 181.5 | 182.6 | 180.4 |
| 110.0 | 177.7 | 182.5 | 183.7 | 181.3 |
| 112.0 | 178.6 | 183.7 | 184.7 | 182.3 |
| 114.0 | 179.8 | 184.7 | 185.8 | 183.4 |
| 116.0 | 180.6 | 186.0 | 186.6 | 184.4 |
| 118.0 | 181.4 | 186.6 | 187.5 | 185.2 |
| 120.0 | 182.1 | 187.6 | 188.4 | 186.0 |

**APPENDIX A3. Average temperature of corn oil heated in susceptor material for three minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 23.2            | 22.9    | 22.7    | 22.9    |
| 2.0     | 26.4            | 24.7    | 28.6    | 26.6    |
| 4.0     | 26.8            | 25.3    | 31.8    | 28.0    |
| 6.0     | 31.5            | 29.5    | 36.5    | 32.5    |
| 8.0     | 36.2            | 32.3    | 40.4    | 36.3    |
| 10.0    | 39.3            | 35.3    | 43.8    | 39.5    |
| 12.0    | 43.3            | 38.3    | 46.9    | 42.8    |
| 14.0    | 45.8            | 40.9    | 49.5    | 45.4    |
| 16.0    | 48.5            | 44.0    | 51.8    | 48.1    |
| 18.0    | 51.2            | 47.7    | 55.0    | 51.3    |
| 20.0    | 55.2            | 50.8    | 58.3    | 54.8    |
| 22.0    | 59.7            | 53.7    | 61.3    | 58.2    |
| 24.0    | 64.3            | 56.9    | 64.9    | 62.0    |
| 26.0    | 68.8            | 60.0    | 67.9    | 65.6    |
| 28.0    | 72.7            | 62.9    | 70.9    | 68.8    |
| 30.0    | 76.2            | 66.5    | 73.5    | 72.1    |
| 32.0    | 78.9            | 69.1    | 76.3    | 74.8    |
| 34.0    | 83.1            | 72.8    | 78.5    | 78.1    |
| 36.0    | 86.9            | 75.9    | 80.9    | 81.2    |
| 38.0    | 91.2            | 79.3    | 83.8    | 84.8    |
| 40.0    | 95.5            | 82.8    | 86.3    | 88.2    |
| 42.0    | 98.6            | 86.1    | 88.3    | 91.0    |
| 44.0    | 104.7           | 89.8    | 90.9    | 95.1    |
| 46.0    | 109.2           | 92.6    | 93.7    | 98.5    |
| 48.0    | 115.6           | 96.1    | 97.0    | 102.9   |
| 50.0    | 117.7           | 99.8    | 100.9   | 106.1   |
| 52.0    | 120.0           | 103.2   | 106.4   | 109.9   |
| 54.0    | 123.4           | 107.4   | 110.8   | 113.9   |
| 56.0    | 126.7           | 111.0   | 115.6   | 117.8   |
| 58.0    | 130.4           | 114.7   | 119.0   | 121.4   |
| 60.0    | 135.8           | 118.1   | 123.1   | 125.7   |
| 62.0    | 140.1           | 122.2   | 126.5   | 129.6   |
| 64.0    | 143.3           | 125.7   | 129.4   | 132.8   |
| 66.0    | 146.3           | 129.4   | 133.9   | 136.5   |
| 68.0    | 148.1           | 132.8   | 135.7   | 138.9   |
| 70.0    | 150.6           | 133.4   | 136.2   | 140.1   |
| 72.0    | 152.8           | 136.6   | 138.1   | 142.5   |
| 74.0    | 154.4           | 139.8   | 140.6   | 144.9   |
| 76.0    | 156.7           | 141.4   | 143.5   | 147.2   |
| 78.0    | 158.6           | 143.8   | 146.1   | 149.5   |
| 80.0    | 160.6           | 145.8   | 149.1   | 151.8   |

## APPENDIX A3 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 82.0  | 162.2 | 148.3 | 152.2 | 154.2 |
| 84.0  | 163.7 | 150.7 | 155.3 | 156.6 |
| 86.0  | 165.6 | 153.6 | 157.6 | 158.9 |
| 88.0  | 167.1 | 155.9 | 160.3 | 161.1 |
| 90.0  | 168.3 | 157.3 | 162.8 | 162.8 |
| 92.0  | 169.8 | 159.9 | 165.0 | 164.9 |
| 94.0  | 171.1 | 161.9 | 166.8 | 166.6 |
| 96.0  | 172.1 | 164.1 | 168.2 | 168.1 |
| 98.0  | 172.9 | 165.7 | 169.7 | 169.4 |
| 100.0 | 174.1 | 167.4 | 171.4 | 171.0 |
| 102.0 | 175.6 | 169.4 | 172.9 | 172.6 |
| 104.0 | 176.5 | 171.1 | 174.2 | 173.9 |
| 106.0 | 177.4 | 172.2 | 175.1 | 174.9 |
| 108.0 | 177.9 | 174.0 | 176.7 | 176.2 |
| 110.0 | 178.8 | 175.3 | 177.6 | 177.2 |
| 112.0 | 179.8 | 176.8 | 178.6 | 178.4 |
| 114.0 | 180.5 | 178.2 | 179.4 | 179.4 |
| 116.0 | 181.0 | 178.6 | 180.1 | 179.9 |
| 118.0 | 181.5 | 178.8 | 181.2 | 180.5 |
| 120.0 | 181.8 | 179.3 | 182.4 | 181.2 |
| 122.0 | 182.4 | 179.6 | 183.5 | 181.8 |
| 124.0 | 182.8 | 180.1 | 184.4 | 182.4 |
| 126.0 | 183.0 | 180.9 | 185.7 | 183.2 |
| 128.0 | 183.0 | 181.2 | 186.2 | 183.5 |
| 130.0 | 183.5 | 181.8 | 187.2 | 184.2 |
| 132.0 | 183.9 | 182.4 | 187.8 | 184.7 |
| 134.0 | 184.4 | 183.0 | 188.6 | 185.3 |
| 136.0 | 185.2 | 184.1 | 188.8 | 186.0 |
| 138.0 | 185.6 | 185.0 | 189.3 | 186.6 |
| 140.0 | 186.2 | 186.0 | 189.9 | 187.4 |
| 142.0 | 186.7 | 186.9 | 190.6 | 188.1 |
| 144.0 | 187.3 | 187.8 | 191.2 | 188.8 |
| 146.0 | 187.9 | 188.6 | 191.7 | 189.4 |
| 148.0 | 188.3 | 189.4 | 192.6 | 190.1 |
| 150.0 | 188.9 | 190.1 | 192.9 | 190.6 |
| 152.0 | 189.0 | 191.0 | 193.6 | 191.2 |
| 154.0 | 189.1 | 191.6 | 194.3 | 191.7 |
| 156.0 | 189.9 | 192.4 | 194.7 | 192.3 |
| 158.0 | 189.9 | 193.1 | 195.6 | 192.9 |
| 160.0 | 189.9 | 193.3 | 196.2 | 193.1 |
| 162.0 | 190.3 | 194.0 | 196.7 | 193.7 |
| 164.0 | 190.6 | 194.4 | 197.3 | 194.1 |
| 166.0 | 191.0 | 194.7 | 197.7 | 194.5 |
| 168.0 | 191.1 | 195.1 | 198.2 | 194.8 |
| 170.0 | 191.4 | 195.6 | 198.7 | 195.2 |

**APPENDIX A3 (con't)**

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 172.0 | 191.4 | 195.9 | 198.8 | 195.4 |
| 174.0 | 191.6 | 196.4 | 198.9 | 195.6 |
| 176.0 | 191.9 | 196.9 | 199.0 | 195.9 |
| 178.0 | 192.1 | 197.0 | 199.3 | 196.1 |
| 180.0 | 192.9 | 197.4 | 199.5 | 196.6 |

**APPENDIX A4. Average temperature of corn oil heated in susceptor material for four minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 23.8            | 23.4    | 23.5    | 23.6    |
| 2.0     | 25.3            | 25.5    | 25.4    | 25.4    |
| 4.0     | 28.0            | 29.4    | 28.7    | 28.7    |
| 6.0     | 30.6            | 31.7    | 30.8    | 31.0    |
| 8.0     | 33.5            | 34.1    | 33.5    | 33.7    |
| 10.0    | 35.9            | 36.8    | 35.9    | 36.2    |
| 12.0    | 38.5            | 39.8    | 38.4    | 38.9    |
| 14.0    | 41.6            | 42.5    | 36.5    | 40.2    |
| 16.0    | 44.6            | 46.1    | 39.6    | 43.4    |
| 18.0    | 47.5            | 49.3    | 42.5    | 46.4    |
| 20.0    | 50.7            | 52.6    | 45.6    | 49.6    |
| 22.0    | 53.6            | 55.8    | 48.4    | 52.6    |
| 24.0    | 56.1            | 58.5    | 51.0    | 55.2    |
| 26.0    | 59.9            | 61.6    | 54.4    | 58.6    |
| 28.0    | 63.2            | 64.2    | 57.3    | 61.6    |
| 30.0    | 66.2            | 67.2    | 60.3    | 64.6    |
| 32.0    | 69.2            | 70.2    | 63.4    | 67.6    |
| 34.0    | 72.4            | 72.9    | 66.3    | 70.5    |
| 36.0    | 75.2            | 75.8    | 69.0    | 73.3    |
| 38.0    | 78.1            | 78.9    | 72.3    | 76.4    |
| 40.0    | 81.6            | 82.6    | 75.8    | 80.0    |
| 42.0    | 84.8            | 85.5    | 78.8    | 83.0    |
| 44.0    | 87.9            | 88.2    | 81.8    | 86.0    |
| 46.0    | 90.9            | 91.6    | 85.0    | 89.2    |
| 48.0    | 94.2            | 94.3    | 87.9    | 92.1    |
| 50.0    | 97.2            | 97.3    | 90.9    | 95.1    |
| 52.0    | 100.6           | 100.9   | 94.4    | 98.6    |
| 54.0    | 104.9           | 104.4   | 98.0    | 102.4   |
| 56.0    | 109.0           | 107.9   | 101.6   | 106.2   |
| 58.0    | 112.4           | 111.1   | 104.8   | 109.4   |
| 60.0    | 115.5           | 114.1   | 107.9   | 112.5   |
| 62.0    | 118.3           | 117.3   | 110.9   | 115.5   |
| 64.0    | 121.3           | 121.0   | 114.3   | 118.9   |
| 66.0    | 125.9           | 125.5   | 118.8   | 123.4   |
| 68.0    | 130.3           | 129.6   | 123.0   | 127.6   |
| 70.0    | 134.5           | 133.9   | 126.9   | 131.8   |
| 72.0    | 139.2           | 137.2   | 130.6   | 135.7   |
| 74.0    | 143.7           | 140.4   | 134.1   | 139.4   |
| 76.0    | 146.6           | 143.8   | 137.2   | 142.5   |
| 78.0    | 148.4           | 147.7   | 140.7   | 145.6   |
| 80.0    | 151.8           | 130.3   | 151.8   | 144.6   |

## APPENDIX A4 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 82.0  | 153.8 | 153.1 | 147.1 | 151.3 |
| 84.0  | 155.3 | 154.7 | 149.7 | 153.2 |
| 86.0  | 157.6 | 157.6 | 153.0 | 156.1 |
| 88.0  | 160.3 | 160.4 | 155.8 | 158.8 |
| 90.0  | 163.0 | 163.2 | 158.2 | 161.5 |
| 92.0  | 165.0 | 165.0 | 160.6 | 163.5 |
| 94.0  | 167.4 | 167.1 | 162.8 | 165.8 |
| 96.0  | 168.9 | 169.7 | 164.6 | 167.7 |
| 98.0  | 170.7 | 170.9 | 166.4 | 169.3 |
| 100.0 | 171.5 | 171.7 | 167.8 | 170.3 |
| 102.0 | 172.1 | 173.4 | 169.5 | 171.7 |
| 104.0 | 173.6 | 174.7 | 171.1 | 173.1 |
| 106.0 | 175.0 | 175.5 | 172.6 | 174.4 |
| 108.0 | 176.3 | 176.4 | 173.9 | 175.5 |
| 110.0 | 177.3 | 177.4 | 175.1 | 176.6 |
| 112.0 | 178.6 | 178.5 | 176.2 | 177.8 |
| 114.0 | 180.0 | 179.9 | 177.3 | 179.1 |
| 116.0 | 180.8 | 181.2 | 178.5 | 180.2 |
| 118.0 | 181.7 | 182.4 | 179.7 | 181.3 |
| 120.0 | 182.8 | 183.5 | 180.9 | 182.4 |
| 122.0 | 183.7 | 184.3 | 181.8 | 183.3 |
| 124.0 | 184.6 | 185.0 | 182.7 | 184.1 |
| 126.0 | 185.3 | 185.8 | 178.9 | 183.3 |
| 128.0 | 185.9 | 186.4 | 179.5 | 183.9 |
| 130.0 | 186.3 | 187.4 | 180.2 | 184.6 |
| 132.0 | 187.2 | 188.1 | 180.9 | 185.4 |
| 134.0 | 187.7 | 188.9 | 181.6 | 186.1 |
| 136.0 | 188.4 | 189.4 | 182.2 | 186.7 |
| 138.0 | 188.9 | 189.9 | 182.9 | 187.2 |
| 140.0 | 189.4 | 189.9 | 183.1 | 187.5 |
| 142.0 | 189.9 | 190.2 | 183.9 | 188.0 |
| 144.0 | 190.3 | 190.4 | 184.5 | 188.4 |
| 146.0 | 190.4 | 190.9 | 187.1 | 189.5 |
| 148.0 | 191.3 | 191.1 | 187.7 | 190.0 |
| 150.0 | 191.7 | 191.6 | 188.3 | 190.5 |
| 152.0 | 192.4 | 191.5 | 188.9 | 190.9 |
| 154.0 | 192.9 | 191.6 | 189.4 | 191.3 |
| 156.0 | 193.4 | 192.5 | 190.2 | 192.0 |
| 158.0 | 193.7 | 193.0 | 190.4 | 192.4 |
| 160.0 | 193.9 | 193.3 | 191.0 | 192.7 |
| 162.0 | 194.0 | 193.7 | 192.0 | 193.2 |
| 164.0 | 194.3 | 194.1 | 192.3 | 193.6 |
| 166.0 | 194.5 | 194.3 | 192.7 | 193.8 |
| 168.0 | 194.4 | 194.2 | 193.2 | 193.9 |
| 170.0 | 194.8 | 194.6 | 193.4 | 194.3 |
| 172.0 | 194.9 | 195.0 | 193.7 | 194.5 |
| 174.0 | 195.1 | 195.4 | 194.0 | 194.8 |

## APPENDIX A4 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 176.0 | 195.0 | 195.8 | 194.5 | 195.1 |
| 178.0 | 195.3 | 196.2 | 194.8 | 195.4 |
| 180.0 | 195.7 | 196.5 | 195.0 | 195.7 |
| 182.0 | 196.0 | 196.6 | 195.4 | 196.0 |
| 184.0 | 196.4 | 196.9 | 195.5 | 196.3 |
| 186.0 | 196.8 | 197.0 | 195.8 | 196.5 |
| 188.0 | 197.3 | 197.6 | 196.0 | 197.0 |
| 190.0 | 197.7 | 198.1 | 196.4 | 197.4 |
| 192.0 | 198.1 | 198.5 | 196.8 | 197.8 |
| 194.0 | 198.0 | 198.8 | 197.0 | 197.9 |
| 196.0 | 198.4 | 199.3 | 197.5 | 198.4 |
| 198.0 | 198.9 | 199.6 | 197.7 | 198.7 |
| 200.0 | 199.4 | 199.8 | 197.9 | 199.0 |
| 202.0 | 199.9 | 200.2 | 198.2 | 199.4 |
| 204.0 | 200.2 | 200.0 | 198.2 | 199.5 |
| 206.0 | 200.1 | 200.5 | 198.6 | 199.7 |
| 208.0 | 200.5 | 200.9 | 198.9 | 200.1 |
| 210.0 | 200.8 | 201.3 | 199.2 | 200.4 |
| 212.0 | 201.2 | 201.6 | 199.5 | 200.8 |
| 214.0 | 201.7 | 210.9 | 202.7 | 205.1 |
| 216.0 | 202.0 | 202.2 | 199.9 | 201.4 |
| 218.0 | 202.4 | 202.7 | 200.3 | 201.8 |
| 220.0 | 202.8 | 203.0 | 200.6 | 202.1 |
| 222.0 | 203.1 | 203.4 | 200.8 | 202.4 |
| 224.0 | 203.4 | 203.7 | 200.9 | 202.7 |
| 226.0 | 203.9 | 204.1 | 201.1 | 203.0 |
| 228.0 | 204.1 | 204.6 | 201.4 | 203.4 |
| 230.0 | 204.0 | 204.5 | 201.5 | 203.3 |
| 232.0 | 204.3 | 205.0 | 201.8 | 203.7 |
| 234.0 | 204.6 | 205.4 | 202.1 | 204.0 |
| 236.0 | 205.0 | 205.9 | 202.6 | 204.5 |
| 238.0 | 205.3 | 206.3 | 203.0 | 204.9 |
| 240.0 | 205.9 | 206.8 | 203.4 | 205.4 |

**APPENDIX A5. Average temperature of corn oil heated in susceptor material for five minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 20.6            | 20.3    | 21.7    | 20.9    |
| 2.0     | 20.7            | 20.3    | 21.9    | 21.0    |
| 4.0     | 23.6            | 21.4    | 26.5    | 23.8    |
| 6.0     | 26.6            | 23.7    | 32.0    | 27.4    |
| 8.0     | 30.2            | 26.2    | 38.6    | 31.7    |
| 10.0    | 33.0            | 28.9    | 47.7    | 36.5    |
| 12.0    | 36.1            | 32.2    | 59.5    | 42.6    |
| 14.0    | 38.4            | 35.6    | 68.2    | 47.4    |
| 16.0    | 40.3            | 38.1    | 75.3    | 51.2    |
| 18.0    | 43.3            | 39.4    | 81.7    | 54.8    |
| 20.0    | 45.5            | 42.8    | 89.1    | 59.1    |
| 22.0    | 47.6            | 46.6    | 94.3    | 62.8    |
| 24.0    | 49.7            | 49.9    | 100.0   | 66.5    |
| 26.0    | 52.1            | 52.7    | 103.6   | 69.4    |
| 28.0    | 54.4            | 55.6    | 107.4   | 72.5    |
| 30.0    | 56.5            | 58.2    | 111.1   | 75.3    |
| 32.0    | 59.3            | 61.1    | 114.7   | 78.4    |
| 34.0    | 61.8            | 64.5    | 118.0   | 81.4    |
| 36.0    | 63.3            | 67.5    | 121.2   | 84.0    |
| 38.0    | 65.7            | 70.2    | 123.4   | 86.4    |
| 40.0    | 67.8            | 72.1    | 125.5   | 88.4    |
| 42.0    | 69.6            | 75.5    | 128.4   | 91.1    |
| 44.0    | 71.2            | 79.1    | 130.9   | 93.7    |
| 46.0    | 72.8            | 82.1    | 131.9   | 95.6    |
| 48.0    | 74.8            | 85.1    | 132.5   | 97.5    |
| 50.0    | 77.3            | 87.8    | 133.9   | 99.7    |
| 52.0    | 79.0            | 89.8    | 134.9   | 101.2   |
| 54.0    | 81.0            | 91.3    | 135.8   | 102.7   |
| 56.0    | 82.5            | 93.8    | 137.8   | 104.7   |
| 58.0    | 84.5            | 95.7    | 139.0   | 106.4   |
| 60.0    | 86.1            | 97.7    | 140.7   | 108.2   |
| 62.0    | 87.2            | 100.6   | 142.1   | 110.0   |
| 64.0    | 88.7            | 103.3   | 144.2   | 112.1   |
| 66.0    | 89.8            | 105.2   | 146.7   | 113.9   |
| 68.0    | 91.4            | 106.8   | 148.3   | 115.5   |
| 70.0    | 92.9            | 109.8   | 150.0   | 117.6   |
| 72.0    | 94.7            | 111.7   | 151.9   | 119.4   |
| 74.0    | 95.9            | 113.4   | 153.5   | 120.9   |
| 76.0    | 97.5            | 115.9   | 155.5   | 123.0   |
| 78.0    | 98.9            | 118.6   | 157.3   | 124.9   |
| 80.0    | 100.5           | 120.4   | 159.4   | 126.8   |



## APPENDIX A5 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 82.0  | 101.6 | 122.3 | 160.3 | 128.0 |
| 84.0  | 103.0 | 124.7 | 161.1 | 129.6 |
| 86.0  | 104.8 | 126.6 | 162.1 | 131.2 |
| 88.0  | 106.3 | 128.9 | 162.9 | 132.7 |
| 90.0  | 108.1 | 130.8 | 163.6 | 134.1 |
| 92.0  | 109.8 | 132.5 | 164.2 | 135.5 |
| 94.0  | 111.6 | 133.6 | 165.3 | 136.8 |
| 96.0  | 112.7 | 135.2 | 166.1 | 138.0 |
| 98.0  | 114.4 | 137.3 | 166.9 | 139.5 |
| 100.0 | 116.2 | 138.9 | 167.5 | 140.8 |
| 102.0 | 118.1 | 141.0 | 169.3 | 142.8 |
| 104.0 | 120.2 | 141.8 | 171.0 | 144.3 |
| 106.0 | 121.2 | 144.0 | 173.2 | 146.1 |
| 108.0 | 122.4 | 145.9 | 175.2 | 147.8 |
| 110.0 | 122.9 | 147.9 | 176.5 | 149.1 |
| 112.0 | 124.2 | 149.3 | 177.8 | 150.4 |
| 114.0 | 125.7 | 150.3 | 178.4 | 151.5 |
| 116.0 | 126.8 | 152.0 | 179.2 | 152.7 |
| 118.0 | 128.1 | 153.3 | 180.2 | 153.8 |
| 120.0 | 129.5 | 152.9 | 181.5 | 154.6 |
| 122.0 | 130.8 | 154.2 | 182.5 | 155.8 |
| 124.0 | 131.8 | 155.7 | 184.0 | 157.1 |
| 126.0 | 132.3 | 147.5 | 185.5 | 155.1 |
| 128.0 | 133.9 | 158.3 | 186.2 | 159.4 |
| 130.0 | 134.5 | 158.9 | 187.7 | 160.4 |
| 132.0 | 135.3 | 160.5 | 188.2 | 161.3 |
| 134.0 | 136.4 | 162.1 | 189.3 | 162.6 |
| 136.0 | 137.6 | 164.0 | 189.9 | 163.8 |
| 138.0 | 137.9 | 165.6 | 190.4 | 164.6 |
| 140.0 | 138.6 | 167.2 | 190.9 | 165.6 |
| 142.0 | 140.0 | 168.8 | 191.2 | 166.7 |
| 144.0 | 141.0 | 170.0 | 191.9 | 167.6 |
| 146.0 | 142.1 | 171.1 | 192.5 | 168.5 |
| 148.0 | 143.4 | 172.2 | 193.2 | 169.6 |
| 150.0 | 144.2 | 174.1 | 194.4 | 170.9 |
| 152.0 | 145.5 | 175.4 | 195.4 | 172.1 |
| 154.0 | 146.8 | 176.5 | 195.9 | 173.1 |
| 156.0 | 148.3 | 177.2 | 196.3 | 173.9 |
| 158.0 | 149.4 | 179.0 | 197.0 | 175.1 |
| 160.0 | 150.1 | 180.2 | 198.1 | 176.1 |
| 162.0 | 151.3 | 181.5 | 199.3 | 177.4 |
| 164.0 | 152.4 | 183.0 | 200.0 | 178.5 |
| 166.0 | 153.1 | 184.3 | 200.5 | 179.3 |
| 168.0 | 154.5 | 185.6 | 201.1 | 180.4 |
| 170.0 | 155.7 | 186.3 | 201.6 | 181.2 |
| 172.0 | 156.8 | 187.0 | 202.2 | 182.0 |
| 174.0 | 157.7 | 188.4 | 202.9 | 183.0 |

## APPENDIX A5 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 176.0 | 158.7 | 189.5 | 203.2 | 183.8 |
| 178.0 | 159.8 | 190.5 | 204.1 | 184.8 |
| 180.0 | 160.6 | 191.4 | 204.8 | 185.6 |
| 182.0 | 161.8 | 192.6 | 205.2 | 186.5 |
| 184.0 | 163.2 | 193.6 | 205.6 | 187.5 |
| 186.0 | 164.1 | 195.0 | 205.9 | 188.3 |
| 188.0 | 164.9 | 195.8 | 206.3 | 189.0 |
| 190.0 | 165.9 | 197.7 | 206.7 | 190.1 |
| 192.0 | 166.8 | 198.9 | 207.1 | 190.9 |
| 194.0 | 167.8 | 199.7 | 207.7 | 191.7 |
| 196.0 | 168.4 | 200.3 | 208.2 | 192.3 |
| 198.0 | 169.0 | 201.1 | 208.6 | 192.9 |
| 200.0 | 169.9 | 201.5 | 209.0 | 193.5 |
| 202.0 | 170.5 | 202.3 | 209.8 | 194.2 |
| 204.0 | 171.1 | 202.9 | 210.3 | 194.8 |
| 206.0 | 171.8 | 203.6 | 210.7 | 195.4 |
| 208.0 | 172.8 | 204.1 | 210.6 | 195.8 |
| 210.0 | 173.4 | 204.5 | 210.8 | 196.2 |
| 212.0 | 173.8 | 205.0 | 211.2 | 196.7 |
| 214.0 | 174.7 | 205.4 | 211.7 | 197.2 |
| 216.0 | 175.3 | 205.6 | 212.1 | 197.6 |
| 218.0 | 176.2 | 205.8 | 212.2 | 198.1 |
| 220.0 | 177.1 | 205.8 | 212.5 | 198.5 |
| 222.0 | 177.9 | 206.2 | 212.9 | 199.0 |
| 224.0 | 178.6 | 206.5 | 212.8 | 199.3 |
| 226.0 | 179.2 | 206.9 | 213.3 | 199.8 |
| 228.0 | 180.0 | 207.5 | 213.6 | 200.4 |
| 230.0 | 180.8 | 208.1 | 213.7 | 200.9 |
| 232.0 | 181.3 | 208.4 | 213.9 | 201.2 |
| 234.0 | 182.2 | 208.7 | 214.3 | 201.7 |
| 236.0 | 182.9 | 208.9 | 214.6 | 202.1 |
| 238.0 | 183.8 | 209.2 | 214.9 | 202.6 |
| 240.0 | 184.5 | 209.5 | 215.3 | 203.1 |
| 242.0 | 185.5 | 209.6 | 215.5 | 203.5 |
| 244.0 | 186.7 | 209.7 | 215.8 | 204.1 |
| 246.0 | 187.6 | 209.9 | 216.1 | 204.5 |
| 248.0 | 188.9 | 210.2 | 216.7 | 205.3 |
| 250.0 | 190.1 | 210.5 | 216.9 | 205.8 |
| 252.0 | 191.0 | 210.6 | 217.3 | 206.3 |
| 254.0 | 192.3 | 210.8 | 217.9 | 207.0 |
| 256.0 | 193.2 | 211.0 | 218.3 | 207.5 |
| 258.0 | 194.3 | 211.3 | 218.7 | 208.1 |
| 260.0 | 195.0 | 211.4 | 219.3 | 208.6 |
| 262.0 | 196.6 | 211.6 | 219.2 | 209.1 |
| 264.0 | 197.2 | 211.8 | 219.4 | 209.4 |
| 266.0 | 198.4 | 212.1 | 219.8 | 210.1 |
| 268.0 | 199.3 | 212.5 | 220.0 | 210.6 |

**APPENDIX A5 (con't)**

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 270.0 | 200.1 | 212.6 | 220.3 | 211.0 |
| 272.0 | 201.6 | 212.9 | 220.2 | 211.6 |
| 274.0 | 202.3 | 213.2 | 220.4 | 212.0 |
| 276.0 | 203.2 | 213.5 | 220.7 | 212.5 |
| 278.0 | 204.1 | 213.7 | 220.9 | 212.9 |
| 280.0 | 204.8 | 214.0 | 221.3 | 213.3 |
| 282.0 | 205.7 | 214.2 | 221.4 | 213.8 |
| 284.0 | 206.2 | 214.3 | 221.8 | 214.1 |
| 286.0 | 207.0 | 214.4 | 222.1 | 214.5 |
| 288.0 | 207.5 | 214.6 | 222.7 | 214.9 |
| 290.0 | 208.8 | 214.8 | 222.9 | 215.5 |
| 292.0 | 209.7 | 215.0 | 223.1 | 215.9 |
| 294.0 | 210.3 | 215.1 | 223.7 | 216.3 |
| 296.0 | 211.1 | 214.1 | 224.2 | 216.5 |
| 298.0 | 212.1 | 215.4 | 224.8 | 217.4 |
| 300.0 | 212.6 | 215.7 | 225.3 | 217.8 |

**APPENDIX A6. Average temperature of corn oil heated in susceptor material for six minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 23.1            | 22.2    | 23.0    | 22.8    |
| 2.0     | 23.3            | 22.2    | 23.3    | 22.9    |
| 4.0     | 27.6            | 24.3    | 27.0    | 26.3    |
| 6.0     | 33.3            | 28.0    | 30.4    | 30.6    |
| 8.0     | 37.3            | 31.0    | 33.1    | 33.8    |
| 10.0    | 40.9            | 33.5    | 36.1    | 36.8    |
| 12.0    | 43.0            | 35.5    | 38.1    | 38.9    |
| 14.0    | 46.4            | 38.5    | 41.6    | 42.2    |
| 16.0    | 50.5            | 42.9    | 44.0    | 45.8    |
| 18.0    | 55.8            | 47.4    | 47.3    | 50.2    |
| 20.0    | 61.8            | 52.8    | 50.3    | 55.0    |
| 22.0    | 68.0            | 57.6    | 58.8    | 61.5    |
| 24.0    | 74.4            | 61.6    | 62.2    | 66.1    |
| 26.0    | 80.8            | 65.6    | 68.2    | 71.5    |
| 28.0    | 87.3            | 69.6    | 72.8    | 76.6    |
| 30.0    | 92.6            | 73.1    | 79.0    | 81.6    |
| 32.0    | 97.7            | 76.4    | 83.6    | 85.9    |
| 34.0    | 102.0           | 79.3    | 85.2    | 88.8    |
| 36.0    | 107.0           | 82.9    | 88.4    | 92.8    |
| 38.0    | 111.2           | 85.5    | 94.6    | 97.1    |
| 40.0    | 114.1           | 87.9    | 99.6    | 100.5   |
| 42.0    | 117.0           | 90.1    | 103.3   | 103.5   |
| 44.0    | 120.7           | 93.0    | 107.4   | 107.0   |
| 46.0    | 123.6           | 95.1    | 111.1   | 109.9   |
| 48.0    | 125.7           | 97.1    | 117.3   | 113.4   |
| 50.0    | 128.7           | 99.6    | 120.9   | 116.4   |
| 52.0    | 131.9           | 102.9   | 125.7   | 120.2   |
| 54.0    | 135.5           | 105.1   | 129.2   | 123.3   |
| 56.0    | 138.1           | 107.1   | 133.0   | 126.1   |
| 58.0    | 140.4           | 108.0   | 135.4   | 127.9   |
| 60.0    | 143.0           | 108.3   | 137.8   | 129.7   |
| 62.0    | 145.4           | 108.7   | 139.4   | 131.2   |
| 64.0    | 147.3           | 109.2   | 141.9   | 132.8   |
| 66.0    | 148.6           | 109.8   | 143.6   | 134.0   |
| 68.0    | 150.7           | 110.0   | 145.1   | 135.3   |
| 70.0    | 152.4           | 110.6   | 148.8   | 137.3   |
| 72.0    | 154.0           | 111.1   | 150.9   | 138.7   |
| 74.0    | 155.3           | 111.9   | 152.8   | 140.0   |
| 76.0    | 156.8           | 112.2   | 154.9   | 141.3   |
| 78.0    | 158.3           | 112.6   | 157.3   | 142.7   |
| 80.0    | 159.1           | 113.7   | 159.0   | 143.9   |

## APPENDIX A6 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 82.0  | 159.9 | 114.9 | 160.8 | 145.2 |
| 84.0  | 160.7 | 116.2 | 162.3 | 146.4 |
| 86.0  | 162.1 | 118.2 | 163.8 | 148.0 |
| 88.0  | 163.4 | 119.8 | 165.2 | 149.5 |
| 90.0  | 165.0 | 121.4 | 166.6 | 151.0 |
| 92.0  | 166.6 | 123.5 | 168.5 | 152.9 |
| 94.0  | 167.8 | 124.3 | 170.2 | 154.1 |
| 96.0  | 169.0 | 125.8 | 171.3 | 155.4 |
| 98.0  | 170.3 | 126.8 | 171.9 | 156.3 |
| 100.0 | 171.2 | 128.0 | 173.1 | 157.4 |
| 102.0 | 172.1 | 129.4 | 173.6 | 158.4 |
| 104.0 | 173.4 | 132.9 | 174.1 | 160.1 |
| 106.0 | 174.8 | 133.3 | 174.7 | 160.9 |
| 108.0 | 175.9 | 134.4 | 175.4 | 161.9 |
| 110.0 | 176.6 | 135.2 | 176.8 | 162.9 |
| 112.0 | 177.4 | 135.5 | 177.5 | 163.5 |
| 114.0 | 178.4 | 137.3 | 177.9 | 164.5 |
| 116.0 | 179.0 | 138.0 | 179.0 | 165.3 |
| 118.0 | 179.6 | 138.6 | 179.7 | 166.0 |
| 120.0 | 180.1 | 138.9 | 180.4 | 166.5 |
| 122.0 | 181.0 | 139.1 | 181.1 | 167.1 |
| 124.0 | 181.6 | 139.6 | 181.9 | 167.7 |
| 126.0 | 182.3 | 139.9 | 182.5 | 168.2 |
| 128.0 | 182.6 | 140.3 | 183.1 | 168.7 |
| 130.0 | 183.0 | 140.4 | 184.3 | 169.2 |
| 132.0 | 183.4 | 141.4 | 185.3 | 170.0 |
| 134.0 | 183.8 | 141.7 | 186.1 | 170.5 |
| 136.0 | 184.2 | 142.3 | 186.5 | 171.0 |
| 138.0 | 185.0 | 143.0 | 187.2 | 171.7 |
| 140.0 | 185.7 | 144.2 | 187.8 | 172.6 |
| 142.0 | 185.5 | 144.2 | 188.1 | 172.6 |
| 144.0 | 185.9 | 145.0 | 188.7 | 173.2 |
| 146.0 | 186.1 | 146.1 | 189.2 | 173.8 |
| 148.0 | 186.6 | 147.5 | 189.6 | 174.6 |
| 150.0 | 187.0 | 148.6 | 190.1 | 175.2 |
| 152.0 | 186.9 | 151.1 | 190.5 | 176.2 |
| 154.0 | 187.3 | 152.6 | 191.1 | 177.0 |
| 156.0 | 188.2 | 154.4 | 191.6 | 178.1 |
| 158.0 | 188.9 | 155.7 | 192.0 | 178.9 |
| 160.0 | 189.2 | 157.6 | 192.9 | 179.9 |
| 162.0 | 189.0 | 160.0 | 193.5 | 180.8 |
| 164.0 | 189.4 | 161.5 | 194.1 | 181.7 |
| 166.0 | 189.8 | 162.6 | 194.7 | 182.4 |
| 168.0 | 190.3 | 163.4 | 195.2 | 183.0 |
| 170.0 | 191.2 | 164.3 | 195.4 | 183.6 |
| 172.0 | 191.6 | 165.2 | 195.5 | 184.1 |

## APPENDIX A6 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 174.0 | 192.0 | 165.8 | 195.8 | 184.5 |
| 176.0 | 191.9 | 166.2 | 196.2 | 184.8 |
| 178.0 | 192.3 | 166.9 | 196.5 | 185.2 |
| 180.0 | 192.9 | 167.3 | 196.4 | 185.5 |
| 182.0 | 193.3 | 167.8 | 196.9 | 186.0 |
| 184.0 | 193.6 | 168.4 | 197.2 | 186.4 |
| 186.0 | 193.4 | 168.9 | 197.6 | 186.6 |
| 188.0 | 193.7 | 169.7 | 197.4 | 186.9 |
| 190.0 | 194.0 | 169.5 | 197.9 | 187.1 |
| 192.0 | 194.4 | 169.9 | 198.2 | 187.5 |
| 194.0 | 194.9 | 170.4 | 198.7 | 188.0 |
| 196.0 | 195.3 | 171.8 | 198.9 | 188.7 |
| 198.0 | 195.2 | 172.1 | 199.2 | 188.8 |
| 200.0 | 195.1 | 172.9 | 199.7 | 189.2 |
| 202.0 | 195.3 | 173.3 | 200.2 | 189.6 |
| 204.0 | 195.6 | 173.9 | 200.3 | 189.9 |
| 206.0 | 196.0 | 174.5 | 200.5 | 190.3 |
| 208.0 | 196.5 | 174.8 | 201.6 | 191.0 |
| 210.0 | 196.7 | 174.7 | 201.9 | 191.1 |
| 212.0 | 197.2 | 175.2 | 202.5 | 191.6 |
| 214.0 | 197.5 | 175.9 | 203.4 | 192.3 |
| 216.0 | 198.1 | 176.9 | 203.9 | 193.0 |
| 218.0 | 198.4 | 177.4 | 203.9 | 193.2 |
| 220.0 | 198.8 | 177.9 | 204.1 | 193.6 |
| 222.0 | 199.2 | 178.3 | 204.6 | 194.0 |
| 224.0 | 199.7 | 178.8 | 205.3 | 194.6 |
| 226.0 | 200.2 | 179.4 | 205.9 | 195.2 |
| 228.0 | 200.7 | 179.7 | 206.0 | 195.5 |
| 230.0 | 201.1 | 180.1 | 205.9 | 195.7 |
| 232.0 | 201.0 | 179.9 | 206.3 | 195.7 |
| 234.0 | 201.1 | 180.3 | 207.0 | 196.1 |
| 236.0 | 201.4 | 180.7 | 207.5 | 196.5 |
| 238.0 | 201.9 | 181.1 | 207.9 | 197.0 |
| 240.0 | 202.5 | 181.0 | 208.2 | 197.2 |
| 242.0 | 202.9 | 181.4 | 208.5 | 197.6 |
| 244.0 | 203.4 | 182.1 | 209.1 | 198.2 |
| 246.0 | 203.8 | 182.8 | 209.8 | 198.8 |
| 248.0 | 204.1 | 183.3 | 210.3 | 199.2 |
| 250.0 | 204.6 | 184.2 | 210.7 | 199.8 |
| 252.0 | 204.9 | 184.7 | 211.1 | 200.2 |
| 254.0 | 205.3 | 185.0 | 211.7 | 200.7 |
| 256.0 | 205.2 | 185.7 | 211.9 | 200.9 |
| 258.0 | 205.7 | 186.6 | 212.2 | 201.5 |
| 260.0 | 205.9 | 187.4 | 212.6 | 202.0 |
| 262.0 | 206.1 | 188.2 | 212.7 | 202.3 |
| 264.0 | 206.9 | 189.1 | 213.0 | 203.0 |

## APPENDIX A6 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 266.0 | 207.2 | 189.5 | 213.5 | 203.4 |
| 268.0 | 207.7 | 190.0 | 213.9 | 203.9 |
| 270.0 | 208.1 | 190.3 | 214.2 | 204.2 |
| 272.0 | 208.7 | 191.5 | 214.8 | 205.0 |
| 274.0 | 209.0 | 192.3 | 215.5 | 205.6 |
| 276.0 | 208.9 | 193.0 | 216.1 | 206.0 |
| 278.0 | 209.4 | 193.6 | 216.0 | 206.3 |
| 280.0 | 209.8 | 194.2 | 216.4 | 206.8 |
| 282.0 | 210.3 | 194.9 | 216.8 | 207.3 |
| 284.0 | 210.8 | 195.5 | 217.3 | 207.9 |
| 286.0 | 211.4 | 196.0 | 217.7 | 208.4 |
| 288.0 | 212.0 | 196.5 | 218.0 | 208.8 |
| 290.0 | 212.5 | 197.1 | 218.4 | 209.3 |
| 292.0 | 212.9 | 197.8 | 218.8 | 209.8 |
| 294.0 | 213.4 | 198.4 | 219.1 | 210.3 |
| 296.0 | 213.9 | 198.9 | 219.6 | 210.8 |
| 298.0 | 214.5 | 199.4 | 219.7 | 211.2 |
| 300.0 | 215.1 | 200.1 | 220.0 | 211.7 |
| 302.0 | 215.0 | 200.7 | 221.3 | 212.3 |
| 304.0 | 215.6 | 201.5 | 221.8 | 213.0 |
| 306.0 | 216.1 | 202.1 | 222.4 | 213.5 |
| 308.0 | 216.9 | 202.8 | 222.8 | 214.2 |
| 310.0 | 217.3 | 203.3 | 223.4 | 214.7 |
| 312.0 | 217.8 | 204.7 | 223.9 | 215.5 |
| 314.0 | 218.3 | 205.3 | 224.3 | 216.0 |
| 316.0 | 219.0 | 205.9 | 224.3 | 216.4 |
| 318.0 | 219.5 | 206.4 | 224.6 | 216.8 |
| 320.0 | 219.4 | 207.0 | 224.9 | 217.1 |
| 322.0 | 219.8 | 207.6 | 225.2 | 217.5 |
| 324.0 | 220.2 | 208.1 | 225.5 | 217.9 |
| 326.0 | 220.5 | 208.9 | 225.9 | 218.4 |
| 328.0 | 220.8 | 209.4 | 226.1 | 218.8 |
| 330.0 | 220.7 | 209.9 | 226.5 | 219.0 |
| 332.0 | 221.0 | 210.3 | 226.7 | 219.3 |
| 334.0 | 221.5 | 210.8 | 226.6 | 219.6 |
| 336.0 | 221.9 | 211.5 | 227.0 | 220.1 |
| 338.0 | 222.4 | 211.8 | 227.1 | 220.4 |
| 340.0 | 222.8 | 212.3 | 227.6 | 220.9 |
| 342.0 | 223.1 | 212.7 | 228.0 | 221.3 |
| 344.0 | 223.6 | 213.0 | 228.2 | 221.6 |
| 346.0 | 223.9 | 214.4 | 228.6 | 222.3 |
| 348.0 | 224.3 | 214.9 | 229.1 | 222.8 |
| 350.0 | 224.2 | 215.0 | 229.4 | 222.9 |
| 352.0 | 224.7 | 215.5 | 229.7 | 223.3 |

**APPENDIX A6 (con't)**

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 354.0 | 225.0 | 216.1 | 230.1 | 223.7 |
| 356.0 | 225.2 | 216.9 | 230.2 | 224.1 |
| 358.0 | 225.8 | 217.7 | 230.5 | 224.7 |
| 360.0 | 226.1 | 218.3 | 230.7 | 225.0 |



**APPENDIX A7. Temperature profile of corn oil heated in susceptor material for seven minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 23.3            | 23.5    | 23.1    | 23.3    |
| 2.0     | 26.2            | 25.7    | 24.1    | 25.3    |
| 4.0     | 29.7            | 28.9    | 28.0    | 28.9    |
| 6.0     | 35.2            | 33.3    | 36.1    | 34.8    |
| 8.0     | 38.8            | 38.5    | 41.6    | 39.6    |
| 10.0    | 41.8            | 41.9    | 45.3    | 43.0    |
| 12.0    | 45.1            | 45.8    | 48.9    | 46.6    |
| 14.0    | 49.8            | 50.9    | 53.3    | 51.4    |
| 16.0    | 54.4            | 56.6    | 59.7    | 56.9    |
| 18.0    | 60.0            | 61.3    | 65.6    | 62.3    |
| 20.0    | 64.1            | 67.5    | 75.0    | 68.8    |
| 22.0    | 67.7            | 72.9    | 78.4    | 73.0    |
| 24.0    | 71.7            | 78.0    | 83.1    | 77.6    |
| 26.0    | 76.5            | 83.2    | 88.4    | 82.7    |
| 28.0    | 80.9            | 87.8    | 93.0    | 87.2    |
| 30.0    | 84.7            | 92.3    | 98.5    | 91.8    |
| 32.0    | 88.2            | 96.5    | 104.6   | 96.4    |
| 34.0    | 92.4            | 100.7   | 109.1   | 100.7   |
| 36.0    | 97.8            | 105.2   | 111.8   | 104.9   |
| 38.0    | 101.7           | 109.2   | 115.4   | 108.8   |
| 40.0    | 105.0           | 112.9   | 120.7   | 112.9   |
| 42.0    | 107.9           | 115.8   | 123.2   | 115.6   |
| 44.0    | 111.8           | 118.2   | 125.5   | 118.5   |
| 46.0    | 115.1           | 120.4   | 127.1   | 120.9   |
| 48.0    | 117.6           | 122.5   | 129.3   | 123.1   |
| 50.0    | 120.3           | 124.7   | 131.8   | 125.6   |
| 52.0    | 122.4           | 126.9   | 133.7   | 127.7   |
| 54.0    | 124.6           | 129.1   | 135.8   | 129.8   |
| 56.0    | 126.6           | 131.1   | 137.7   | 131.8   |
| 58.0    | 128.5           | 133.2   | 139.2   | 133.6   |
| 60.0    | 130.4           | 134.6   | 140.8   | 135.3   |
| 62.0    | 133.7           | 136.5   | 142.9   | 137.7   |
| 64.0    | 136.4           | 138.3   | 144.4   | 139.7   |
| 66.0    | 139.1           | 140.0   | 146.2   | 141.8   |
| 68.0    | 138.3           | 141.7   | 147.7   | 142.6   |
| 70.0    | 142.6           | 143.7   | 150.3   | 145.5   |
| 72.0    | 144.2           | 145.6   | 152.3   | 147.4   |
| 74.0    | 146.3           | 147.1   | 153.6   | 149.0   |
| 76.0    | 148.6           | 148.2   | 154.1   | 150.3   |
| 78.0    | 149.9           | 149.5   | 155.1   | 151.5   |
| 80.0    | 152.0           | 150.9   | 156.2   | 153.0   |

## APPENDIX A7 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 82.0  | 153.9 | 152.0 | 157.1 | 154.3 |
| 84.0  | 155.6 | 153.2 | 158.1 | 155.6 |
| 86.0  | 157.4 | 154.4 | 159.0 | 156.9 |
| 88.0  | 158.6 | 155.3 | 160.1 | 158.0 |
| 90.0  | 159.8 | 156.2 | 160.9 | 159.0 |
| 92.0  | 160.9 | 157.1 | 161.7 | 159.9 |
| 94.0  | 161.9 | 158.1 | 162.5 | 160.8 |
| 96.0  | 163.1 | 159.2 | 163.7 | 162.0 |
| 98.0  | 164.5 | 160.7 | 165.3 | 163.5 |
| 100.0 | 165.7 | 161.7 | 166.2 | 164.5 |
| 102.0 | 166.4 | 162.6 | 166.8 | 165.3 |
| 104.0 | 167.5 | 163.3 | 167.3 | 166.0 |
| 106.0 | 168.8 | 163.7 | 167.8 | 166.8 |
| 108.0 | 169.8 | 164.6 | 168.6 | 167.7 |
| 110.0 | 170.7 | 165.1 | 168.9 | 168.2 |
| 112.0 | 171.7 | 165.9 | 169.4 | 169.0 |
| 114.0 | 172.4 | 166.6 | 169.9 | 169.6 |
| 116.0 | 173.1 | 167.4 | 170.4 | 170.3 |
| 118.0 | 174.2 | 168.1 | 170.6 | 171.0 |
| 120.0 | 175.2 | 168.8 | 171.2 | 171.7 |
| 122.0 | 175.9 | 169.5 | 171.7 | 172.4 |
| 124.0 | 176.5 | 170.2 | 172.4 | 173.0 |
| 126.0 | 177.2 | 170.8 | 172.8 | 173.6 |
| 128.0 | 178.2 | 171.3 | 173.6 | 174.4 |
| 130.0 | 178.8 | 171.9 | 173.9 | 174.9 |
| 132.0 | 179.7 | 172.5 | 174.9 | 175.7 |
| 134.0 | 180.5 | 173.0 | 175.3 | 176.3 |
| 136.0 | 181.7 | 173.3 | 175.6 | 176.9 |
| 138.0 | 183.0 | 173.7 | 176.2 | 177.6 |
| 140.0 | 183.9 | 174.3 | 177.0 | 178.4 |
| 142.0 | 184.6 | 174.9 | 177.9 | 179.1 |
| 144.0 | 185.3 | 175.2 | 178.3 | 179.6 |
| 146.0 | 186.1 | 175.7 | 179.0 | 180.3 |
| 148.0 | 187.1 | 176.1 | 179.5 | 180.9 |
| 150.0 | 187.8 | 176.7 | 180.3 | 181.6 |
| 152.0 | 188.5 | 177.3 | 181.1 | 182.3 |
| 154.0 | 189.3 | 178.0 | 181.9 | 183.1 |
| 156.0 | 190.0 | 178.6 | 182.7 | 183.8 |
| 158.0 | 190.5 | 179.1 | 183.0 | 184.2 |
| 160.0 | 191.3 | 179.6 | 183.5 | 184.8 |
| 162.0 | 192.0 | 180.0 | 184.0 | 185.3 |
| 164.0 | 192.5 | 180.5 | 184.6 | 185.9 |
| 166.0 | 193.3 | 180.9 | 185.0 | 186.4 |
| 168.0 | 193.8 | 181.5 | 185.8 | 187.0 |
| 170.0 | 194.2 | 182.0 | 186.4 | 187.5 |
| 172.0 | 194.7 | 182.4 | 186.9 | 188.0 |
| 174.0 | 195.4 | 183.1 | 187.6 | 188.7 |

## APPENDIX A7 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 176.0 | 196.3 | 183.5 | 187.9 | 189.2 |
| 178.0 | 197.0 | 184.0 | 188.2 | 189.8 |
| 180.0 | 197.9 | 184.5 | 188.6 | 190.3 |
| 182.0 | 198.7 | 185.0 | 189.1 | 190.9 |
| 184.0 | 199.7 | 185.4 | 189.8 | 191.6 |
| 186.0 | 200.5 | 186.0 | 190.3 | 192.2 |
| 188.0 | 201.4 | 186.4 | 190.8 | 192.9 |
| 190.0 | 202.6 | 186.7 | 191.2 | 193.5 |
| 192.0 | 203.2 | 187.4 | 191.7 | 194.1 |
| 194.0 | 204.1 | 188.1 | 192.3 | 194.8 |
| 196.0 | 204.7 | 188.7 | 192.7 | 195.4 |
| 198.0 | 205.6 | 189.2 | 193.5 | 196.1 |
| 200.0 | 206.3 | 189.7 | 193.9 | 196.6 |
| 202.0 | 207.4 | 190.1 | 194.1 | 197.2 |
| 204.0 | 207.9 | 190.5 | 194.5 | 197.6 |
| 206.0 | 208.8 | 191.0 | 194.8 | 198.2 |
| 208.0 | 209.6 | 191.5 | 195.4 | 198.8 |
| 210.0 | 210.7 | 192.0 | 196.0 | 199.5 |
| 212.0 | 211.2 | 192.4 | 196.6 | 200.1 |
| 214.0 | 211.5 | 193.0 | 197.0 | 200.5 |
| 216.0 | 212.0 | 193.3 | 197.4 | 200.9 |
| 218.0 | 212.2 | 193.8 | 197.5 | 201.2 |
| 220.0 | 212.4 | 194.3 | 198.0 | 201.5 |
| 222.0 | 212.7 | 194.8 | 198.5 | 202.0 |
| 224.0 | 212.8 | 195.3 | 198.9 | 202.3 |
| 226.0 | 213.0 | 195.9 | 199.5 | 202.8 |
| 228.0 | 213.3 | 196.4 | 200.2 | 203.3 |
| 230.0 | 213.6 | 196.9 | 200.7 | 203.8 |
| 232.0 | 213.9 | 197.2 | 201.2 | 204.1 |
| 234.0 | 214.1 | 197.6 | 201.6 | 204.4 |
| 236.0 | 214.4 | 197.9 | 202.2 | 204.8 |
| 238.0 | 214.7 | 198.2 | 202.3 | 205.1 |
| 240.0 | 215.1 | 198.7 | 202.6 | 205.5 |
| 242.0 | 215.7 | 199.2 | 203.1 | 206.0 |
| 244.0 | 215.9 | 199.5 | 203.0 | 206.1 |
| 246.0 | 216.1 | 200.0 | 203.3 | 206.5 |
| 248.0 | 216.5 | 200.5 | 203.8 | 206.9 |
| 250.0 | 216.7 | 201.1 | 204.2 | 207.3 |
| 252.0 | 217.1 | 201.6 | 204.9 | 207.9 |
| 254.0 | 217.2 | 202.1 | 205.5 | 208.3 |
| 256.0 | 217.4 | 202.6 | 206.0 | 208.7 |
| 258.0 | 217.7 | 203.1 | 206.4 | 209.1 |
| 260.0 | 218.0 | 203.5 | 206.9 | 209.5 |
| 262.0 | 218.3 | 204.0 | 207.2 | 209.9 |
| 264.0 | 218.5 | 204.5 | 207.8 | 210.3 |
| 266.0 | 218.8 | 205.0 | 208.3 | 210.7 |
| 268.0 | 219.1 | 205.6 | 208.9 | 211.2 |

## APPENDIX A7 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 270.0 | 219.4 | 206.0 | 209.4 | 211.6 |
| 272.0 | 219.6 | 206.4 | 209.9 | 212.0 |
| 274.0 | 219.8 | 206.9 | 210.3 | 212.3 |
| 276.0 | 220.1 | 207.2 | 210.7 | 212.6 |
| 278.0 | 220.2 | 207.6 | 211.0 | 213.0 |
| 280.0 | 220.5 | 208.1 | 211.4 | 213.3 |
| 282.0 | 220.6 | 208.6 | 211.8 | 213.7 |
| 284.0 | 221.0 | 209.2 | 212.3 | 214.2 |
| 286.0 | 221.3 | 209.7 | 212.6 | 214.5 |
| 288.0 | 221.5 | 210.2 | 213.0 | 214.9 |
| 290.0 | 221.6 | 210.9 | 213.5 | 215.3 |
| 292.0 | 221.9 | 211.4 | 213.9 | 215.7 |
| 294.0 | 222.1 | 211.8 | 214.3 | 216.1 |
| 296.0 | 222.4 | 212.4 | 214.8 | 216.5 |
| 298.0 | 222.6 | 212.8 | 215.1 | 216.8 |
| 300.0 | 223.0 | 213.3 | 215.7 | 217.3 |
| 302.0 | 223.7 | 213.8 | 216.2 | 217.9 |
| 304.0 | 223.9 | 214.2 | 216.6 | 218.2 |
| 306.0 | 224.1 | 214.7 | 217.1 | 218.6 |
| 308.0 | 224.3 | 215.3 | 217.8 | 219.1 |
| 310.0 | 224.5 | 215.9 | 218.4 | 219.6 |
| 312.0 | 224.8 | 216.3 | 218.9 | 220.0 |
| 314.0 | 225.4 | 216.8 | 219.5 | 220.5 |
| 316.0 | 225.5 | 217.2 | 220.0 | 220.9 |
| 318.0 | 225.8 | 217.6 | 220.4 | 221.3 |
| 320.0 | 226.1 | 218.1 | 220.9 | 221.7 |
| 322.0 | 226.4 | 218.6 | 221.3 | 222.1 |
| 324.0 | 226.6 | 219.0 | 221.7 | 222.4 |
| 326.0 | 226.8 | 219.5 | 222.2 | 222.8 |
| 328.0 | 227.0 | 220.1 | 222.8 | 223.3 |
| 330.0 | 227.4 | 220.5 | 223.3 | 223.7 |
| 332.0 | 227.6 | 221.0 | 223.7 | 224.1 |
| 334.0 | 227.9 | 221.6 | 224.1 | 224.5 |
| 336.0 | 228.0 | 222.1 | 224.6 | 224.9 |
| 338.0 | 228.3 | 222.6 | 225.0 | 225.3 |
| 340.0 | 228.6 | 223.0 | 225.6 | 225.7 |
| 342.0 | 228.8 | 223.6 | 226.2 | 226.2 |
| 344.0 | 229.0 | 224.1 | 226.7 | 226.6 |
| 346.0 | 229.2 | 224.5 | 227.4 | 227.0 |
| 348.0 | 229.5 | 224.9 | 227.9 | 227.4 |
| 350.0 | 229.7 | 225.3 | 228.5 | 227.9 |
| 352.0 | 229.9 | 226.1 | 229.9 | 228.6 |
| 354.0 | 230.1 | 226.6 | 230.6 | 229.1 |
| 356.0 | 230.4 | 227.1 | 231.0 | 229.5 |
| 358.0 | 230.7 | 227.9 | 232.7 | 230.4 |
| 360.0 | 230.9 | 228.6 | 233.3 | 230.9 |
| 362.0 | 231.1 | 229.1 | 234.1 | 231.4 |

## APPENDIX A7 (con't)

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 364.0 | 231.5 | 229.7 | 234.8 | 232.0 |
| 366.0 | 231.7 | 230.2 | 235.5 | 232.5 |
| 368.0 | 232.0 | 230.6 | 236.0 | 232.9 |
| 370.0 | 232.2 | 231.2 | 236.7 | 233.4 |
| 372.0 | 232.4 | 231.6 | 237.4 | 233.8 |
| 374.0 | 232.7 | 232.2 | 238.1 | 234.3 |
| 376.0 | 232.9 | 232.7 | 238.9 | 234.8 |
| 378.0 | 233.2 | 233.3 | 239.6 | 235.3 |
| 380.0 | 233.4 | 233.8 | 240.3 | 235.8 |
| 382.0 | 233.5 | 234.4 | 240.9 | 236.3 |
| 384.0 | 233.7 | 234.8 | 241.5 | 236.7 |
| 386.0 | 234.0 | 235.2 | 241.8 | 237.0 |
| 388.0 | 234.3 | 235.7 | 242.5 | 237.5 |
| 390.0 | 234.4 | 236.2 | 243.0 | 237.9 |
| 392.0 | 234.7 | 236.7 | 243.6 | 238.3 |
| 394.0 | 235.1 | 237.2 | 244.2 | 238.8 |
| 396.0 | 235.4 | 237.7 | 244.9 | 239.3 |
| 398.0 | 235.6 | 238.2 | 245.4 | 239.8 |
| 400.0 | 235.5 | 238.8 | 246.0 | 240.1 |
| 402.0 | 235.9 | 239.4 | 246.8 | 240.7 |
| 404.0 | 236.2 | 240.0 | 247.6 | 241.2 |
| 406.0 | 236.4 | 240.5 | 248.2 | 241.7 |
| 408.0 | 236.6 | 241.1 | 248.9 | 242.2 |
| 410.0 | 236.9 | 232.5 | 249.3 | 239.6 |
| 412.0 | 237.1 | 242.0 | 249.8 | 243.0 |
| 414.0 | 237.4 | 242.5 | 250.3 | 243.4 |
| 416.0 | 237.5 | 243.0 | 250.8 | 243.8 |
| 418.0 | 237.8 | 243.6 | 251.5 | 244.3 |
| 420.0 | 238.1 | 244.2 | 252.0 | 244.8 |

**APPENDIX A8. Average temperature of corn oil heated in CPET tray for one minute.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 21.7            | 22.3    | 21.7    | 21.9    |
| 4.0     | 22.8            | 23.8    | 22.6    | 23.0    |
| 8.0     | 23.8            | 25.2    | 23.4    | 24.1    |
| 12.0    | 24.8            | 26.3    | 24.1    | 25.1    |
| 16.0    | 25.6            | 27.6    | 24.9    | 26.0    |
| 20.0    | 26.4            | 28.8    | 25.9    | 27.0    |
| 24.0    | 27.1            | 29.9    | 26.3    | 27.8    |
| 28.0    | 27.8            | 30.9    | 27.0    | 28.5    |
| 32.0    | 28.5            | 31.9    | 27.6    | 29.3    |
| 36.0    | 29.3            | 33.0    | 28.2    | 30.1    |
| 40.0    | 29.7            | 34.0    | 28.9    | 30.9    |
| 44.0    | 30.3            | 35.0    | 29.3    | 31.5    |
| 48.0    | 31.0            | 36.0    | 29.9    | 32.3    |
| 52.0    | 31.5            | 36.9    | 30.6    | 33.0    |
| 56.0    | 32.2            | 37.9    | 31.1    | 33.7    |
| 60.0    | 32.3            | 38.8    | 31.8    | 34.3    |

**APPENDIX A9. Average temperature of corn oil heated in CPET tray for two minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 23.3            | 23.4    | 22.7    | 23.1    |
| 4.0     | 23.5            | 24.8    | 23.9    | 24.1    |
| 8.0     | 23.7            | 25.4    | 25.1    | 24.7    |
| 12.0    | 23.8            | 26.5    | 26.1    | 25.5    |
| 16.0    | 23.9            | 27.4    | 26.9    | 26.1    |
| 20.0    | 25.0            | 28.5    | 27.7    | 27.0    |
| 24.0    | 26.2            | 29.2    | 28.7    | 28.0    |
| 28.0    | 27.4            | 30.2    | 29.4    | 29.0    |
| 32.0    | 28.3            | 31.1    | 30.4    | 29.9    |
| 36.0    | 29.3            | 31.9    | 31.2    | 30.8    |
| 40.0    | 30.1            | 32.7    | 32.4    | 31.7    |
| 44.0    | 31.0            | 33.5    | 33.1    | 32.5    |
| 48.0    | 31.9            | 34.2    | 34.2    | 33.4    |
| 52.0    | 32.7            | 34.7    | 35.0    | 34.1    |
| 56.0    | 33.6            | 35.6    | 35.7    | 34.9    |
| 60.0    | 34.4            | 36.4    | 36.7    | 35.8    |
| 64.0    | 35.3            | 37.4    | 37.4    | 36.7    |
| 68.0    | 36.1            | 37.9    | 38.2    | 37.4    |
| 72.0    | 37.0            | 38.8    | 39.0    | 38.3    |
| 76.0    | 37.2            | 39.7    | 39.6    | 38.8    |
| 80.0    | 38.1            | 40.4    | 40.3    | 39.6    |
| 84.0    | 38.8            | 41.2    | 41.1    | 40.4    |
| 88.0    | 39.2            | 42.0    | 42.0    | 41.1    |
| 92.0    | 38.8            | 42.5    | 42.6    | 41.3    |
| 96.0    | 39.2            | 43.0    | 43.1    | 41.8    |
| 100.0   | 40.5            | 43.6    | 43.7    | 42.6    |
| 104.0   | 41.6            | 44.2    | 44.4    | 43.4    |
| 108.0   | 43.1            | 44.7    | 45.1    | 44.3    |
| 112.0   | 44.0            | 45.1    | 45.7    | 44.9    |
| 116.0   | 44.6            | 45.4    | 46.5    | 45.5    |
| 120.0   | 45.1            | 45.9    | 46.4    | 45.8    |

**APPENDIX A10. Average temperature of corn oil heated in CPET tray for three minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 23.8            | 25.1    | 23.1    | 24.0    |
| 4.0     | 25.3            | 25.8    | 24.7    | 25.3    |
| 8.0     | 27.1            | 27.3    | 26.3    | 26.9    |
| 12.0    | 28.6            | 28.8    | 27.5    | 28.3    |
| 16.0    | 30.1            | 29.9    | 28.5    | 29.5    |
| 20.0    | 31.7            | 31.1    | 30.2    | 31.0    |
| 24.0    | 33.0            | 32.1    | 31.4    | 32.2    |
| 28.0    | 34.3            | 33.1    | 32.8    | 33.4    |
| 32.0    | 35.6            | 34.1    | 34.0    | 34.5    |
| 36.0    | 36.8            | 34.9    | 34.9    | 35.5    |
| 40.0    | 38.0            | 35.8    | 35.6    | 36.4    |
| 44.0    | 39.1            | 36.7    | 37.0    | 37.6    |
| 48.0    | 40.0            | 37.6    | 37.9    | 38.5    |
| 52.0    | 41.2            | 38.6    | 38.9    | 39.6    |
| 56.0    | 42.2            | 39.6    | 39.9    | 40.6    |
| 60.0    | 43.5            | 40.5    | 41.1    | 41.7    |
| 64.0    | 44.6            | 41.4    | 41.9    | 42.6    |
| 68.0    | 45.5            | 42.2    | 43.1    | 43.6    |
| 72.0    | 46.6            | 43.0    | 44.1    | 44.6    |
| 76.0    | 47.6            | 43.7    | 45.1    | 45.5    |
| 80.0    | 48.7            | 44.3    | 45.8    | 46.2    |
| 84.0    | 49.7            | 44.9    | 46.8    | 47.1    |
| 88.0    | 50.4            | 45.4    | 47.4    | 47.7    |
| 92.0    | 51.3            | 46.1    | 48.1    | 48.5    |
| 96.0    | 52.1            | 46.4    | 48.8    | 49.1    |
| 100.0   | 52.7            | 46.8    | 50.0    | 49.8    |
| 104.0   | 53.4            | 47.2    | 50.5    | 50.3    |
| 108.0   | 53.9            | 47.7    | 51.1    | 50.9    |
| 112.0   | 54.6            | 48.1    | 51.5    | 51.4    |
| 116.0   | 55.0            | 48.7    | 52.1    | 51.9    |
| 120.0   | 55.5            | 49.0    | 52.7    | 52.4    |
| 124.0   | 56.0            | 49.6    | 53.1    | 52.9    |
| 128.0   | 56.4            | 49.9    | 53.8    | 53.4    |
| 132.0   | 57.0            | 50.6    | 54.3    | 53.9    |
| 136.0   | 57.4            | 51.1    | 54.9    | 54.5    |
| 140.0   | 58.1            | 51.4    | 55.9    | 55.1    |
| 144.0   | 58.7            | 52.2    | 56.5    | 55.8    |
| 148.0   | 59.3            | 52.8    | 57.5    | 56.5    |
| 152.0   | 59.9            | 53.2    | 57.8    | 56.9    |
| 156.0   | 60.6            | 53.8    | 58.1    | 57.5    |
| 160.0   | 61.2            | 54.1    | 58.6    | 58.0    |



**APPENDIX A10 (con't)**

|       |      |      |      |      |
|-------|------|------|------|------|
| 164.0 | 61.7 | 54.8 | 59.0 | 58.5 |
| 168.0 | 62.2 | 55.2 | 59.2 | 58.8 |
| 172.0 | 62.6 | 55.5 | 59.7 | 59.3 |
| 176.0 | 63.1 | 55.9 | 59.7 | 59.6 |
| 180.0 | 64.1 | 56.4 | 59.2 | 59.9 |

**APPENDIX A11. Average temperature of corn oil heated in CPET tray for five minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 23.7            | 23.3    | 23.0    | 23.3    |
| 4.0     | 24.9            | 23.6    | 24.2    | 24.2    |
| 8.0     | 26.1            | 24.9    | 26.1    | 25.7    |
| 12.0    | 27.3            | 26.1    | 27.8    | 27.1    |
| 16.0    | 28.3            | 27.3    | 29.5    | 28.3    |
| 20.0    | 29.2            | 28.3    | 31.0    | 29.5    |
| 24.0    | 30.3            | 29.2    | 32.5    | 30.7    |
| 28.0    | 31.3            | 30.1    | 34.1    | 31.8    |
| 32.0    | 32.2            | 31.1    | 35.7    | 33.0    |
| 36.0    | 33.1            | 31.9    | 37.3    | 34.1    |
| 40.0    | 33.8            | 32.9    | 38.6    | 35.1    |
| 44.0    | 34.8            | 33.7    | 40.1    | 36.2    |
| 48.0    | 35.7            | 34.5    | 41.4    | 37.2    |
| 52.0    | 36.5            | 35.3    | 42.6    | 38.1    |
| 56.0    | 37.5            | 36.1    | 43.7    | 39.1    |
| 60.0    | 38.4            | 37.0    | 45.0    | 40.1    |
| 64.0    | 39.4            | 37.8    | 46.0    | 41.1    |
| 68.0    | 40.3            | 38.8    | 47.1    | 42.1    |
| 72.0    | 41.3            | 39.6    | 48.3    | 43.0    |
| 76.0    | 42.1            | 40.5    | 49.8    | 44.1    |
| 80.0    | 43.2            | 41.1    | 51.1    | 45.1    |
| 84.0    | 44.0            | 42.0    | 52.4    | 46.1    |
| 88.0    | 44.6            | 42.7    | 53.6    | 47.0    |
| 92.0    | 45.4            | 43.4    | 54.7    | 47.8    |
| 96.0    | 46.0            | 44.0    | 56.0    | 48.7    |
| 100.0   | 46.4            | 44.6    | 57.2    | 49.4    |
| 104.0   | 47.0            | 45.1    | 58.2    | 50.1    |
| 108.0   | 47.3            | 45.7    | 59.1    | 50.7    |
| 112.0   | 47.9            | 46.3    | 60.2    | 51.4    |
| 116.0   | 48.5            | 47.1    | 61.0    | 52.2    |
| 120.0   | 48.9            | 47.9    | 61.9    | 52.9    |
| 124.0   | 49.4            | 48.7    | 62.7    | 53.6    |
| 128.0   | 50.1            | 49.4    | 63.4    | 54.3    |
| 132.0   | 50.5            | 50.2    | 64.0    | 54.9    |
| 136.0   | 51.0            | 51.1    | 64.5    | 55.5    |
| 140.0   | 51.6            | 52.0    | 64.9    | 56.2    |
| 144.0   | 52.1            | 52.9    | 65.8    | 56.9    |
| 148.0   | 52.7            | 53.7    | 66.3    | 57.6    |
| 152.0   | 53.0            | 54.8    | 66.7    | 58.2    |
| 156.0   | 53.5            | 55.8    | 67.3    | 58.8    |
| 160.0   | 54.1            | 56.8    | 67.8    | 59.5    |

**APPENDIX A11 (con't)**

|       |      |      |      |      |
|-------|------|------|------|------|
| 164.0 | 54.6 | 57.8 | 68.1 | 60.2 |
| 168.0 | 55.1 | 58.9 | 68.6 | 60.8 |
| 172.0 | 55.8 | 59.9 | 69.1 | 61.6 |
| 176.0 | 56.3 | 61.2 | 69.5 | 62.3 |
| 180.0 | 56.9 | 62.2 | 69.8 | 63.0 |
| 184.0 | 57.6 | 63.3 | 70.6 | 63.8 |
| 188.0 | 58.2 | 64.3 | 71.0 | 64.5 |
| 192.0 | 58.9 | 65.3 | 71.5 | 65.2 |
| 196.0 | 59.4 | 66.3 | 72.0 | 65.9 |
| 200.0 | 59.9 | 67.2 | 72.8 | 66.6 |
| 204.0 | 60.6 | 68.2 | 73.4 | 67.4 |
| 208.0 | 61.1 | 69.1 | 74.3 | 68.2 |
| 212.0 | 61.4 | 70.1 | 75.0 | 68.8 |
| 216.0 | 62.2 | 71.1 | 75.7 | 69.6 |
| 220.0 | 62.6 | 72.0 | 76.3 | 70.3 |
| 224.0 | 63.3 | 73.0 | 77.1 | 71.1 |
| 228.0 | 63.8 | 73.8 | 78.0 | 71.8 |
| 232.0 | 64.3 | 74.7 | 78.7 | 72.5 |
| 236.0 | 64.7 | 75.6 | 79.3 | 73.2 |
| 240.0 | 64.6 | 76.4 | 79.8 | 73.6 |

**APPENDIX A12. Average temperature of corn oil heated in CPET tray for five minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 22.9            | 23.5    | 20.8    | 22.4    |
| 4.0     | 23.4            | 24.7    | 21.1    | 23.1    |
| 8.0     | 25.0            | 26.0    | 22.1    | 24.4    |
| 12.0    | 26.4            | 27.1    | 22.9    | 25.5    |
| 16.0    | 28.0            | 28.5    | 24.0    | 26.8    |
| 20.0    | 29.4            | 29.7    | 24.9    | 28.0    |
| 24.0    | 30.7            | 30.7    | 25.7    | 29.0    |
| 28.0    | 32.1            | 31.8    | 26.4    | 30.1    |
| 32.0    | 33.5            | 32.8    | 27.3    | 31.2    |
| 36.0    | 34.8            | 34.0    | 28.1    | 32.3    |
| 40.0    | 36.2            | 34.8    | 29.0    | 33.3    |
| 44.0    | 37.3            | 35.8    | 29.8    | 34.3    |
| 48.0    | 37.4            | 36.8    | 30.4    | 34.9    |
| 52.0    | 39.6            | 37.7    | 31.3    | 36.2    |
| 56.0    | 40.6            | 38.8    | 32.0    | 37.1    |
| 60.0    | 41.6            | 39.6    | 32.7    | 37.9    |
| 64.0    | 42.8            | 40.4    | 33.6    | 38.9    |
| 68.0    | 43.9            | 41.3    | 34.5    | 39.9    |
| 72.0    | 45.1            | 42.2    | 35.3    | 40.8    |
| 76.0    | 45.8            | 42.8    | 36.2    | 41.6    |
| 80.0    | 47.5            | 43.7    | 37.0    | 42.7    |
| 84.0    | 48.6            | 44.4    | 37.7    | 43.5    |
| 88.0    | 49.7            | 45.0    | 38.5    | 44.4    |
| 92.0    | 48.7            | 45.6    | 39.3    | 44.5    |
| 96.0    | 49.7            | 46.2    | 40.0    | 45.3    |
| 100.0   | 50.6            | 46.5    | 40.5    | 45.9    |
| 104.0   | 51.6            | 47.4    | 41.1    | 46.7    |
| 108.0   | 52.4            | 48.1    | 41.5    | 47.3    |
| 112.0   | 53.5            | 48.7    | 42.1    | 48.1    |
| 116.0   | 54.3            | 49.5    | 42.7    | 48.8    |
| 120.0   | 55.0            | 50.1    | 43.2    | 49.4    |
| 124.0   | 55.7            | 50.9    | 43.7    | 50.1    |
| 128.0   | 56.4            | 51.5    | 44.2    | 50.7    |
| 132.0   | 56.9            | 52.4    | 44.6    | 51.3    |
| 136.0   | 57.5            | 53.2    | 45.2    | 51.9    |
| 140.0   | 58.0            | 54.0    | 45.6    | 52.5    |
| 144.0   | 58.5            | 55.0    | 46.1    | 53.2    |
| 148.0   | 58.9            | 55.7    | 46.5    | 53.7    |
| 152.0   | 59.0            | 56.6    | 47.0    | 54.2    |
| 156.0   | 59.3            | 57.5    | 47.3    | 54.7    |
| 160.0   | 59.6            | 58.4    | 47.9    | 55.3    |

## APPENDIX A12 (con't)

|       |      |      |      |      |
|-------|------|------|------|------|
| 164.0 | 60.0 | 59.3 | 48.4 | 55.9 |
| 168.0 | 60.3 | 60.5 | 48.8 | 56.5 |
| 172.0 | 60.7 | 61.2 | 49.3 | 57.1 |
| 176.0 | 61.2 | 62.3 | 49.9 | 57.8 |
| 180.0 | 61.6 | 63.5 | 50.4 | 58.5 |
| 184.0 | 62.1 | 64.5 | 50.9 | 59.2 |
| 188.0 | 62.8 | 65.3 | 51.3 | 59.8 |
| 192.0 | 63.3 | 66.3 | 51.7 | 60.4 |
| 196.0 | 64.0 | 66.7 | 52.2 | 60.9 |
| 200.0 | 64.6 | 67.9 | 52.7 | 61.7 |
| 204.0 | 65.3 | 68.8 | 53.2 | 62.4 |
| 208.0 | 65.8 | 69.6 | 53.5 | 63.0 |
| 212.0 | 66.5 | 70.4 | 54.2 | 63.7 |
| 216.0 | 67.3 | 71.0 | 54.7 | 64.3 |
| 220.0 | 67.9 | 71.8 | 55.6 | 65.1 |
| 224.0 | 68.6 | 72.5 | 56.9 | 66.0 |
| 228.0 | 69.2 | 73.5 | 58.1 | 66.9 |
| 232.0 | 69.8 | 74.2 | 59.7 | 67.9 |
| 236.0 | 70.6 | 75.0 | 60.8 | 68.8 |
| 240.0 | 71.1 | 75.8 | 61.5 | 69.4 |
| 244.0 | 71.7 | 76.7 | 62.4 | 70.2 |
| 248.0 | 72.1 | 77.5 | 62.7 | 70.7 |
| 252.0 | 72.6 | 78.6 | 63.1 | 71.4 |
| 256.0 | 73.1 | 79.6 | 64.1 | 72.3 |
| 260.0 | 73.5 | 80.5 | 64.5 | 72.8 |
| 264.0 | 74.1 | 81.2 | 65.0 | 73.4 |
| 268.0 | 74.6 | 82.2 | 65.3 | 74.0 |
| 272.0 | 75.0 | 82.9 | 65.6 | 74.5 |
| 276.0 | 75.7 | 83.7 | 66.5 | 75.3 |
| 280.0 | 76.3 | 84.8 | 66.7 | 75.9 |
| 284.0 | 76.5 | 85.7 | 67.3 | 76.5 |
| 288.0 | 77.3 | 86.6 | 67.8 | 77.2 |
| 292.0 | 77.7 | 87.5 | 68.3 | 77.8 |
| 296.0 | 78.2 | 88.5 | 68.8 | 78.5 |
| 300.0 | 78.8 | 88.7 | 69.3 | 78.9 |

**APPENDIX A13. Average temperature of corn oil heated in CPET tray for six minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 22.2            | 21.9    | 23.2    | 22.4    |
| 4.0     | 23.4            | 22.8    | 23.5    | 23.2    |
| 8.0     | 24.8            | 23.9    | 24.7    | 24.5    |
| 12.0    | 25.9            | 24.9    | 25.8    | 25.5    |
| 16.0    | 27.0            | 25.8    | 26.8    | 26.5    |
| 20.0    | 27.9            | 26.7    | 27.8    | 27.4    |
| 24.0    | 29.0            | 27.5    | 28.4    | 28.3    |
| 28.0    | 29.9            | 28.3    | 29.2    | 29.1    |
| 32.0    | 30.7            | 29.1    | 30.1    | 30.0    |
| 36.0    | 31.5            | 29.9    | 30.8    | 30.7    |
| 40.0    | 32.5            | 30.5    | 31.3    | 31.4    |
| 44.0    | 33.5            | 31.4    | 31.9    | 32.2    |
| 48.0    | 34.3            | 32.1    | 32.6    | 33.0    |
| 52.0    | 35.2            | 32.8    | 33.0    | 33.7    |
| 56.0    | 36.1            | 33.5    | 33.6    | 34.4    |
| 60.0    | 36.9            | 34.3    | 34.2    | 35.1    |
| 64.0    | 37.7            | 34.9    | 34.8    | 35.8    |
| 68.0    | 38.4            | 35.6    | 35.2    | 36.4    |
| 72.0    | 39.1            | 36.3    | 35.7    | 37.0    |
| 76.0    | 39.8            | 36.9    | 36.3    | 37.7    |
| 80.0    | 40.5            | 37.7    | 36.6    | 38.2    |
| 84.0    | 40.9            | 38.3    | 37.1    | 38.8    |
| 88.0    | 41.4            | 39.0    | 37.8    | 39.4    |
| 92.0    | 41.8            | 39.5    | 38.5    | 39.9    |
| 96.0    | 42.3            | 40.2    | 39.2    | 40.6    |
| 100.0   | 42.8            | 40.9    | 40.0    | 41.2    |
| 104.0   | 43.5            | 41.4    | 40.7    | 41.9    |
| 108.0   | 44.1            | 42.0    | 41.4    | 42.5    |
| 112.0   | 44.4            | 42.6    | 42.1    | 43.0    |
| 116.0   | 45.0            | 43.2    | 43.0    | 43.7    |
| 120.0   | 45.6            | 43.8    | 43.7    | 44.3    |
| 124.0   | 46.2            | 44.5    | 44.4    | 45.0    |
| 128.0   | 46.7            | 45.1    | 45.1    | 45.6    |
| 132.0   | 47.5            | 45.9    | 45.9    | 46.4    |
| 136.0   | 47.9            | 46.4    | 46.7    | 47.0    |
| 140.0   | 48.8            | 47.1    | 47.2    | 47.7    |
| 144.0   | 49.5            | 48.0    | 48.0    | 48.5    |
| 148.0   | 50.2            | 48.8    | 48.6    | 49.2    |
| 152.0   | 51.0            | 49.4    | 49.3    | 49.9    |
| 156.0   | 51.6            | 50.2    | 49.9    | 50.5    |
| 160.0   | 52.4            | 50.8    | 50.6    | 51.2    |

## APPENDIX A13 (con't)

|       |      |      |      |      |
|-------|------|------|------|------|
| 164.0 | 53.1 | 51.5 | 51.2 | 51.9 |
| 168.0 | 53.9 | 52.2 | 51.9 | 52.7 |
| 172.0 | 54.6 | 52.8 | 52.5 | 53.3 |
| 176.0 | 55.4 | 53.4 | 53.0 | 53.9 |
| 180.0 | 56.0 | 54.1 | 53.8 | 54.6 |
| 184.0 | 56.7 | 54.6 | 54.6 | 55.3 |
| 188.0 | 57.4 | 55.1 | 55.2 | 55.9 |
| 192.0 | 58.2 | 55.9 | 55.9 | 56.7 |
| 196.0 | 58.8 | 56.3 | 56.8 | 57.3 |
| 200.0 | 59.4 | 56.9 | 57.6 | 58.0 |
| 204.0 | 60.2 | 57.4 | 58.4 | 58.7 |
| 208.0 | 60.8 | 58.0 | 59.0 | 59.3 |
| 212.0 | 61.6 | 58.7 | 59.7 | 60.0 |
| 216.0 | 62.2 | 59.1 | 60.4 | 60.5 |
| 220.0 | 62.9 | 59.8 | 61.1 | 61.3 |
| 224.0 | 63.5 | 60.4 | 61.8 | 61.9 |
| 228.0 | 64.2 | 61.1 | 62.6 | 62.6 |
| 232.0 | 64.8 | 61.6 | 63.3 | 63.2 |
| 236.0 | 65.7 | 62.1 | 63.9 | 63.9 |
| 240.0 | 66.3 | 62.6 | 64.6 | 64.5 |
| 244.0 | 67.1 | 63.0 | 65.2 | 65.1 |
| 248.0 | 67.6 | 63.5 | 65.7 | 65.6 |
| 252.0 | 68.4 | 64.0 | 66.4 | 66.3 |
| 256.0 | 69.0 | 64.4 | 66.8 | 66.7 |
| 260.0 | 69.6 | 64.9 | 67.2 | 67.2 |
| 264.0 | 70.2 | 65.4 | 67.4 | 67.7 |
| 268.0 | 71.0 | 66.0 | 67.6 | 68.2 |
| 272.0 | 71.6 | 66.4 | 67.7 | 68.5 |
| 276.0 | 72.2 | 66.9 | 67.7 | 68.9 |
| 280.0 | 72.9 | 67.3 | 67.9 | 69.4 |
| 284.0 | 73.4 | 67.8 | 67.9 | 69.7 |
| 288.0 | 73.9 | 68.1 | 67.9 | 70.0 |
| 292.0 | 74.5 | 68.3 | 68.0 | 70.2 |
| 296.0 | 75.1 | 68.8 | 68.2 | 70.7 |
| 300.0 | 75.7 | 69.1 | 68.4 | 71.0 |
| 304.0 | 76.3 | 69.3 | 68.7 | 71.4 |
| 308.0 | 76.6 | 69.6 | 69.0 | 71.7 |
| 312.0 | 77.3 | 69.8 | 69.3 | 72.2 |
| 316.0 | 77.7 | 70.1 | 69.6 | 72.5 |
| 320.0 | 77.9 | 70.3 | 70.0 | 72.7 |
| 324.0 | 78.2 | 70.5 | 70.3 | 73.0 |
| 328.0 | 78.7 | 70.6 | 70.8 | 73.4 |
| 332.0 | 78.8 | 70.9 | 71.1 | 73.6 |
| 336.0 | 79.2 | 71.0 | 71.5 | 73.9 |
| 340.0 | 79.2 | 71.3 | 72.0 | 74.1 |
| 344.0 | 79.6 | 71.6 | 72.3 | 74.5 |

**APPENDIX A13 (con't)**

|       |      |      |      |      |
|-------|------|------|------|------|
| 348.0 | 79.8 | 72.0 | 72.6 | 74.8 |
| 352.0 | 79.8 | 72.3 | 73.2 | 75.1 |
| 356.0 | 80.0 | 72.7 | 73.6 | 75.4 |
| 360.0 | 79.8 | 73.0 | 74.1 | 75.6 |



**APPENDIX A14. Average temperature of corn oil heated in CPET tray for seven minutes.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Trial 1         | Trial 2 | Trial 3 | Average |
| 0.0     | 23.1            | 22.5    | 23.1    | 22.9    |
| 4.0     | 23.5            | 23.2    | 23.8    | 23.5    |
| 8.0     | 24.7            | 24.3    | 24.8    | 24.6    |
| 12.0    | 26.1            | 25.6    | 25.7    | 25.8    |
| 16.0    | 27.3            | 26.9    | 26.6    | 26.9    |
| 20.0    | 28.4            | 28.0    | 27.4    | 27.9    |
| 24.0    | 29.3            | 29.1    | 28.2    | 28.9    |
| 28.0    | 30.3            | 30.1    | 29.1    | 29.8    |
| 32.0    | 31.1            | 31.3    | 30.0    | 30.8    |
| 36.0    | 32.0            | 32.1    | 30.7    | 31.6    |
| 40.0    | 32.9            | 33.0    | 31.5    | 32.5    |
| 44.0    | 33.7            | 33.8    | 32.4    | 33.3    |
| 48.0    | 34.5            | 34.7    | 33.3    | 34.1    |
| 52.0    | 35.4            | 35.7    | 34.0    | 35.0    |
| 56.0    | 36.2            | 36.4    | 34.9    | 35.8    |
| 60.0    | 37.0            | 37.4    | 35.7    | 36.7    |
| 64.0    | 37.7            | 38.3    | 36.6    | 37.5    |
| 68.0    | 38.4            | 39.2    | 37.4    | 38.3    |
| 72.0    | 39.1            | 39.9    | 38.3    | 39.1    |
| 76.0    | 39.8            | 40.7    | 39.1    | 39.8    |
| 80.0    | 40.1            | 41.4    | 39.9    | 40.5    |
| 84.0    | 40.7            | 42.1    | 40.8    | 41.2    |
| 88.0    | 41.2            | 42.8    | 41.4    | 41.8    |
| 92.0    | 41.5            | 43.5    | 42.0    | 42.3    |
| 96.0    | 42.1            | 44.2    | 42.7    | 43.0    |
| 100.0   | 42.3            | 44.7    | 43.4    | 43.4    |
| 104.0   | 42.7            | 45.3    | 43.9    | 43.9    |
| 108.0   | 43.1            | 45.9    | 44.7    | 44.5    |
| 112.0   | 43.5            | 46.6    | 45.1    | 45.0    |
| 116.0   | 44.0            | 47.2    | 45.7    | 45.6    |
| 120.0   | 44.4            | 47.8    | 46.0    | 46.1    |
| 124.0   | 44.8            | 48.3    | 46.7    | 46.6    |
| 128.0   | 45.2            | 49.1    | 47.2    | 47.1    |
| 132.0   | 45.7            | 49.6    | 47.7    | 47.6    |
| 136.0   | 46.1            | 50.4    | 48.2    | 48.2    |
| 140.0   | 46.5            | 50.9    | 48.7    | 48.7    |
| 144.0   | 47.1            | 51.5    | 49.3    | 49.3    |
| 148.0   | 47.5            | 52.2    | 49.8    | 49.8    |
| 152.0   | 47.9            | 52.9    | 50.4    | 50.4    |
| 156.0   | 48.4            | 53.6    | 50.7    | 50.9    |
| 160.0   | 49.1            | 54.4    | 51.3    | 51.6    |

**APPENDIX A14 (con't)**

|       |      |      |      |      |
|-------|------|------|------|------|
| 164.0 | 49.6 | 55.2 | 51.8 | 52.2 |
| 168.0 | 50.2 | 55.9 | 52.3 | 52.8 |
| 172.0 | 50.8 | 56.7 | 53.0 | 53.5 |
| 176.0 | 51.4 | 57.3 | 53.6 | 54.1 |
| 180.0 | 52.0 | 58.3 | 54.2 | 54.8 |
| 184.0 | 52.7 | 59.1 | 54.7 | 55.5 |
| 188.0 | 53.4 | 59.6 | 55.4 | 56.1 |
| 192.0 | 54.0 | 60.5 | 55.7 | 56.7 |
| 196.0 | 54.5 | 61.3 | 56.3 | 57.3 |
| 200.0 | 55.3 | 61.9 | 56.9 | 58.0 |
| 204.0 | 55.8 | 62.6 | 57.4 | 58.6 |
| 208.0 | 56.5 | 63.3 | 57.9 | 59.2 |
| 212.0 | 57.0 | 63.9 | 58.5 | 59.8 |
| 216.0 | 57.6 | 64.7 | 59.0 | 60.4 |
| 220.0 | 58.1 | 65.3 | 59.5 | 61.0 |
| 224.0 | 58.7 | 65.9 | 60.0 | 61.5 |
| 228.0 | 59.2 | 66.5 | 60.6 | 62.1 |
| 232.0 | 59.8 | 67.1 | 61.1 | 62.6 |
| 236.0 | 60.2 | 67.8 | 61.7 | 63.2 |
| 240.0 | 60.7 | 68.3 | 62.1 | 63.7 |
| 244.0 | 61.2 | 68.9 | 62.5 | 64.2 |
| 248.0 | 61.7 | 69.7 | 63.1 | 64.8 |
| 252.0 | 62.4 | 70.2 | 63.8 | 65.5 |
| 256.0 | 62.8 | 70.8 | 64.5 | 66.0 |
| 260.0 | 63.5 | 71.3 | 64.8 | 66.5 |
| 264.0 | 64.0 | 71.9 | 65.5 | 67.1 |
| 268.0 | 64.5 | 72.3 | 66.0 | 67.6 |
| 272.0 | 65.0 | 72.9 | 66.5 | 68.1 |
| 276.0 | 65.5 | 73.5 | 67.0 | 68.6 |
| 280.0 | 66.0 | 74.1 | 67.6 | 69.2 |
| 284.0 | 66.4 | 74.9 | 68.0 | 69.8 |
| 288.0 | 67.0 | 75.5 | 68.6 | 70.4 |
| 292.0 | 67.5 | 76.1 | 69.1 | 70.9 |
| 296.0 | 67.7 | 76.6 | 69.7 | 71.3 |
| 300.0 | 65.5 | 77.5 | 70.2 | 71.0 |
| 304.0 | 68.7 | 77.8 | 70.6 | 72.4 |
| 308.0 | 69.1 | 78.3 | 71.1 | 72.8 |
| 312.0 | 69.7 | 78.8 | 71.6 | 73.4 |
| 316.0 | 70.2 | 79.3 | 72.0 | 73.8 |
| 320.0 | 70.6 | 79.7 | 72.4 | 74.2 |
| 324.0 | 71.0 | 80.2 | 72.9 | 74.7 |
| 328.0 | 71.3 | 80.8 | 73.6 | 75.2 |
| 332.0 | 71.7 | 81.1 | 73.8 | 75.5 |
| 336.0 | 72.1 | 81.4 | 74.5 | 76.0 |
| 340.0 | 72.3 | 81.6 | 74.9 | 76.3 |
| 344.0 | 72.5 | 81.9 | 75.3 | 76.6 |
| 348.0 | 72.8 | 82.0 | 75.6 | 76.8 |

**APPENDIX A14 (con't)**

|       |      |      |      |      |
|-------|------|------|------|------|
| 352.0 | 72.9 | 82.2 | 76.1 | 77.0 |
| 356.0 | 73.2 | 82.6 | 76.3 | 77.3 |
| 360.0 | 73.4 | 82.8 | 76.5 | 77.5 |
| 364.0 | 73.6 | 82.8 | 76.7 | 77.7 |
| 368.0 | 73.9 | 82.9 | 76.9 | 77.9 |
| 372.0 | 74.3 | 83.0 | 77.2 | 78.1 |
| 376.0 | 74.8 | 82.9 | 77.4 | 78.4 |
| 380.0 | 75.3 | 82.7 | 77.7 | 78.5 |
| 384.0 | 75.9 | 82.6 | 78.0 | 78.8 |
| 388.0 | 76.3 | 82.7 | 78.3 | 79.1 |
| 392.0 | 76.8 | 82.7 | 78.7 | 79.4 |
| 396.0 | 77.2 | 82.9 | 79.1 | 79.7 |
| 400.0 | 77.9 | 83.1 | 79.6 | 80.2 |
| 404.0 | 78.5 | 83.3 | 79.9 | 80.6 |
| 408.0 | 78.9 | 83.6 | 80.3 | 80.9 |
| 412.0 | 79.4 | 83.8 | 80.7 | 81.3 |
| 416.0 | 79.9 | 84.2 | 80.8 | 81.6 |
| 420.0 | 80.3 | 84.3 | 81.1 | 81.9 |

**APPENDIX B. Temperature recorded by the four probes at four interface locations in the susceptor material after one minute of exposure.**

| Time, s | Temperature, °C |         |         |         |
|---------|-----------------|---------|---------|---------|
|         | Probe 1         | Probe 2 | Probe 3 | Probe 4 |
| 0       | 23.9            | 23.0    | 23.5    | 23.5    |
| 2       | 24.2            | 24.5    | 24.7    | 24.6    |
| 4       | 25.5            | 25.6    | 28.6    | 25.0    |
| 6       | 29.8            | 26.3    | 33.1    | 26.6    |
| 8       | 38.5            | 31.2    | 39.8    | 33.9    |
| 10      | 51.0            | 38.5    | 47.3    | 49.4    |
| 12      | 57.4            | 42.0    | 50.6    | 60.3    |
| 14      | 63.5            | 45.1    | 55.0    | 67.7    |
| 16      | 67.7            | 47.5    | 61.5    | 73.6    |
| 18      | 71.6            | 50.8    | 67.8    | 81.1    |
| 20      | 74.5            | 55.7    | 74.1    | 90.9    |
| 22      | 74.5            | 62.1    | 82.6    | 103.4   |
| 24      | 73.6            | 65.8    | 88.1    | 106.8   |
| 26      | 76.8            | 69.4    | 93.5    | 106.2   |
| 28      | 80.5            | 73.3    | 95.2    | 107.9   |
| 30      | 82.9            | 77.3    | 99.6    | 110.8   |
| 32      | 86.3            | 81.9    | 102.0   | 115.5   |
| 34      | 89.4            | 86.4    | 105.8   | 119.3   |
| 36      | 92.5            | 92.2    | 108.4   | 122.2   |
| 38      | 95.3            | 97.4    | 112.6   | 124.5   |
| 40      | 97.9            | 100.6   | 115.0   | 127.2   |
| 42      | 100.4           | 103.3   | 118.3   | 130.0   |
| 44      | 103.0           | 107.0   | 122.1   | 132.9   |
| 46      | 105.0           | 110.7   | 125.5   | 135.0   |
| 48      | 107.1           | 115.1   | 127.8   | 136.8   |
| 50      | 109.2           | 119.5   | 130.0   | 138.4   |
| 52      | 111.5           | 124.3   | 132.2   | 140.4   |
| 54      | 113.7           | 128.5   | 134.6   | 142.4   |
| 56      | 115.2           | 133.2   | 136.9   | 144.3   |
| 58      | 115.6           | 134.9   | 138.0   | 146.5   |
| 60      | 115.2           | 135.8   | 139.6   | 148.4   |

**APPENDIX C. Sample calculation of concentration of DMT, DET, and BHET in corn oil extracts from susceptor material.**

The following is a sample calculation of the concentration of DET in corn oil extract after 1 minute exposure in the microwave oven. The calibration factor (CF) of DET is  $9.36 \times 10^{-12}$  g/units and average area response of DET at 1.0 minute is 1473 units. The diameter of the cell was 12.2 cm, giving an exposed area equal to 1.169 dm<sup>2</sup>. Volume of the sample injected was 10 $\mu$ l (0.01 ml) out of a total volume of 2.0 ml.

$$\begin{aligned}
 \text{Concentration } (\mu\text{g/g}) &= \frac{CF \times R_s \times V_{\text{total}}}{V_{\text{inj}} \times A} \\
 &= \frac{9.17 \times 10^{-11} \times 1473 \times 2}{0.01 \times 1.169} \\
 &= 23.2\mu\text{g/dm}^2
 \end{aligned}$$

The concentration of DMT, DET, and BHET listed in Table 5 were calculated in a similar manner.

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