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International Microwave Power Institute
P.O. Box 1140, Mechanicsville, VA 23111 USA
Tel: +1 804.559.6667 – Fax: +1 804.559.4087

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Microwave Ovens and Food Safety: Preparation of Not-Ready-to-Eat Products in Standard and Smart Ovens

Robert F. Schiffmann
R. F. Schiffmann Associates, Inc., 149 West 88 Street, New York, NY 10024 USA

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ABSTRACT

The introduction of several Not-Ready-to-Eat (NRTE) products, beginning in 2007, has resulted in several recalls and has caused serious concerns about their safe-cooking in microwave ovens. These products are not fully-thermally processed prior to sale but depend upon the consumer to finish cooking them to the safe minimum temperatures, defined by the USDA, in order to destroy any sources of foodborne illnesses. While microwave ovens are a primary means of this finish-cooking step, they are known to cook foods unevenly in terms of temperature distribution, especially from a frozen state, and this may cause parts of the food to be below the required safe-temperature. Hence there are concerns regarding how reliably microwave ovens can provide the minimum required safe temperatures in order to avoid the possibility of foodborne illnesses. To determine this, temperature profiling tests were preformed upon three frozen NRTE entrées, heating them in eight new brand-name 1100-watt and 1200-watt microwave ovens in order to evaluate how well the minimum temperatures were reached throughout the products. By comparison, these same tests were repeated using three "smart" microwave ovens in which internal computer-control makes them user-independent. In addition, a comparison was also made of the microwave output power claimed by the manufacturers of these ovens to that determined using the IEC procedures.

KEYWORDS: Microwave ovens, Not-Ready-to-Eat food, NRTE, smart microwave ovens, foodborne illness, food safety, frozen foods

INTRODUCTION

Foodborne illness in the United States is a major concern. An assessment by the CDC, and published in December of 2010 [CDC, 2010], estimated 48 million cases of foodborne illness annually in the USA, of which approximately 3,000 resulted in death. A major cause of foodborne illness is undercooking of food that has been contaminated by a food-pathogen. The USDA and others have published numerous guidelines for the minimum internal temperatures required to ensure food safety [FDA, 2011]. These basically state that the minimum internal temperature must be 160º F to 170 ºF (71.11 °C to 76.66 °C) for meat and poultry; while 145 ºF (62.77 °C) is recommended for fish and seafood products. These are the "safe" temperatures referred to throughout this document.

In the last five years, several food processors introduced "Not-Ready-to-Eat" (NRTE) products into the marketplace. These are products that are not fully thermally processed at the manufacturing facility and depend upon the consumer to finish cooking them to the safe temperature appropriate for each product. By minimally processing these products, manufacturers believe that the eating quality will be improved over Ready-to-Eat (RTE) fully thermally processed products. Therefore, consumers are instructed to finish cooking these products to the safe temperature shown within the microwave cooking instructions on each product's package. Microwave oven heating directions for these products are usually based upon 1100-watt or 1200-watt microwave ovens; consumers with lower wattage ovens are told to adjust the cooking times accordingly.

Based upon US Census figures, it is estimated that there are approximately 120 to 130 million microwave ovens in US homes. A 2011 Consumer Survey Report published by the International Microwave Power Institute [IMPI, 2011] revealed that 82.1% of consumers claim to have microwave ovens with wattages of 900 watts or greater, which indicates that at least 17.9%, or over 20 million ovens, have output-wattages lower than 900 watts. How likely is a math-challenged consumer to be able to calculate the required increase in cooking time? There are many other questions regarding the safe heating of NRTE products, such as:

If kitchen thermometers should be used to determine the final temperature of the food: only 58.9% of respondents to the IMPI 2011 Consumer Survey [IMPI, 2011] have a kitchen thermometer, of which, more than half are dial-type. Importantly, according to the same IMPI Consumer Survey of those who own kitchen thermometers, 58.1% indicated they never use it in conjunction with microwave prepared foods.

As noted later in this paper, the power (wattage) that consumers claim to know may have little relationship to the actual output power.

Microwave ovens heat foods very rapidly and unevenly, due to the non uniformities in microwave distribution within the oven and the changing dielectric properties of the foods during heating. Consumers often do not use sufficient standing time to allow for temperature equilibration by means of conductive heat transfer [Vadivambal and Jayas, 2011].

This research explores how well 1100-watt and 1200-watt microwave ovens cook NRTE products in terms of providing food safety, either by setting the parameters on standard ovens following the NRTE directions provided in the packages or allow the computer of the smart ovens, when available, to do that.

MATERIALS AND METHODS

Food Products

Three well-known frozen NRTE entrée products were purchased in quantity from local supermarkets and transported to the laboratory in ice-containing coolers, where they were stored in a freezer at 5 °F (-15 ºC) for at least 24 hours prior to testing. This ensured equilibration of temperatures throughout each product. The products used in the tests were:

Product # 1. Chicken breast with mashed potatoes and gravy.

Product # 2: Beef cut in small pieces in a sauce and vegetable.

Product # 3: Turkey breast with mashed potatoes, stuffing and gravy.

Food safety criteria

In conventional cooking, the maximum temperature achieved in the food is controlled by the cooking medium. For example, for boiling in water the maximum would be 212 °F (100 °C), while it might be as high as 500 °F (260 °C) for cooking in oil. In oven cooking methods such as baking and broiling, ovens are typically heated to 350 to 400 °F, this temperature, or one close to it, being achieved at the surface of the food; but the interior of the food is likely to be at a lower temperature resulting from conductive heat transfer from the hot surface. While these temperatures are likely to be higher then the minima required for the safe cooking, another important factor for destroying potentially harmful microorganisms is the time that the food remains at these temperatures. Conductive heat transfer in conventional cooking usually results in relatively uniform steady-state temperatures within the interior of foods. However, with microwaves the temperature at any location is largely dependent upon the permittivity of each one of the components in the meal, which results not only in how well the particular component heats, but also the heat-penetration depth into that component. Because microwave heating is usually much more rapid than conventional heating methods, and that the temperature of air in the microwave oven is at, or close to the room temperature, there is little opportunity for conduction to reduce the thermal gradients within these food components, and that can result in large variations in temperature from site to site within each component. In this work it is assumed that reaching or exceeding the minimum cooking temperature recommended in the heating instructions for each product is enough for complying with the safety criteria, while the time at which these temperatures maintained is not considered. Therefore, it was very important to validate that temperatures were really above the safe values, while no tolerances are given regarding the readings.

Standard Microwave Ovens

Eight new microwave ovens, whose manufacturer declared that their power output was in the 1100-1200 watt category, were purchased from local retail stores. Table I is a list of those ovens as well as their model numbers and cavity-capacity, i.e. the cooking-space volume. Three of the ovens were equipped with a computer "smart" feature that was disabled and operated in standard mode in order to have the same setting conditions in the eight ovens. Then, the smart feature was enabled for conducting the second set of tests described in this work.

Smart Microwave Ovens

As explained above, three of the eight ovens had a computer-logic feature known as TrueCookPlus® (TCP), that was enabled for conducting the smart cooking tests to determine their ability to automatically set the oven conditions to safely cook the same three NRTE products. Nothing, but enabling the TCP was changed in the LG, Kenmore #1 and Kenmore #2 ovens (Table I). A "Smart" oven is defined as a microwave oven in which the cooking cycle is controlled by a computer-logic system internal to the oven. Here, the consumer needs only to input information about the product to be cooked

Table I. The eight microwave ovens used in the tests.

Manufacturer	Model #	Capacity (ft^3)	Microwave power (watts)
GE	JES1142SJ	1.1	1100
LG	LRMP1270ST (TCP oven)	1.2	1200
FRIGIDAIRE	FFCM1134LS	1.1	1100
KENMORE #1	721.7915 (TCP oven)	1.5	1200
SHARP	R-408LS	1.4	1100
KENMORE #2	721.66339 (TCP oven)	1.2	1200
MAGIC CHEF	MCD1311ST	1.3	1100
EMERSON	MWG9115SL	1.2	1100

in the form of a numeric code, typically 4 or 5 digits long and provided either on the food's package or the TCP website, that determines the best cooking cycle in terms of time and microwave power. For example, for a particular product, using the oven's keypad, the consumer would input a numeric code, specific to the manner of heating a particular product and the oven's logic system would covert that to a cooking cycle of X minutes @ power level 1, followed by Y minutes @ power level 2, and so on. Further, the logic system adjusts these heating directions for a particular model of microwave oven. The cooking cycle may also incorporate rest times during which there is no microwave power for a predetermined period of time between cooking periods or at the end of microwaving.

Preparation of the microwave ovens

Since the microwave power given by the manufacturer is an averaged number, it does not represent the actual output power of any specific oven. Therefore, an important initial step was to determine the actual microwave output of each oven. All ovens were tested three times each using a modified IEC 705 procedure. 1000 g ± 5 g of tap water @ 10ºC ± 0.1 ˚C, was heated for 62 seconds in a microwave oven operated at 120 volts The water was contained in the specified IEC borosilicate glass beaker (outside diameter 190 mm, thickness 3 mm, such as Pyrex #3140). The glass weight measured with an electronic balance (Acculab V1200 Digital Balance) and the ambient temperature were recorded. At the end of the heating cycle, following vigorous stirring with a glass stirring-rod, the temperature rise was measured using a thermocouple (Fluke Model 51, Series II thermometer and a Type K thermocouple: Fluke Corporation, Everett WA). This data was used to calculate the actual output. Since this test is to be run in a "cold" microwave oven (one that had not been operated for at least 8 hours) it could only be run once a day. In this case, it was run once on three different days for each microwave oven.

A significant reduction in output power during the first several minutes of an oven's use has been experienced. Because of this, each oven was pre-warmed prior to its use for testing the food products. The pre-warming step consisted of heating one-liter of water at full power, in a microwavable container, for 10 minutes, removing the water and allowing the oven to cool down with the oven's door open for at least 15 minutes or until the turntable was no hotter than 27 ºC. If the oven was not used for one hour or more this preheating step was repeated.

Microwave Cooking

The preparation instructions for each product were provided on its package. Also indicated was that all instructions had been developed on 1100-watt microwave ovens, and specific times indicated the number of minutes the product was to be cooked at high power. In addition, two of the products also gave cooking times for 700-watt ovens. Standing times of 1 to 2 minutes were recommended following microwave cooking. All three products indicated that for food safety "…ensure that the product reaches 160 ˚F"; or "…ensure that product reaches an internal temperature of 160 ˚F." Despite these instructions, no product suggested using a kitchen thermometer to check if the product has reached 160 ˚F. The instructions for all products indicated "Ovens vary" and that "cooking time may need to be adjusted".

Test protocol

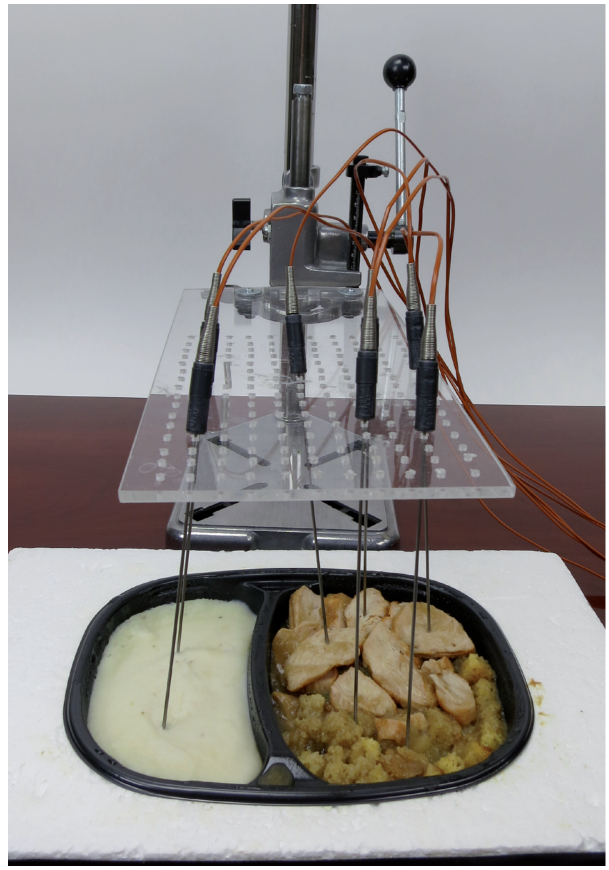
Following the package cooking instructions exactly, each product was prepared and tested in each of the eight microwave ovens. The tests were run in triplicate, i.e. each product was tested three times in each microwave oven, and the order of testing was randomized. No

product was run more than once a day in any oven. Samples were removed from the freezer, one at a time, and cooked in one of the eight pre-warmed microwave ovens.
Smart oven tests of the three NRTE products used product-specific four-digit codes developed at the laboratory of Microwave Science JV LLC (Norcross GA). The TCP oven decompiler uses this code in the oven's logic system to determine the proper cooking or heating cycle for each product by taking into account the oven's thermal operating condition, elevation above sea level microwave performance characteristics and mains voltage environment in order to optimize the cooking cycle for that product.

Temperature measurement

At the end of the microwave cooking cycle, including the recommended standing time, the sample was removed from the oven and immediately placed in a rigid-foam holder constructed to hold that particular tray in a tight fit, thereby reducing heat loss during temperature measurement.

Seven thermocouples (Omega JMTSS-062G, Type 'J' six inches length, 304 Stainless Steel sheath) were held using a "hedgehog" rig shown in Figure 1, and inserted into specific places within the food and temperatures were measured three times in rapid succession at the places noted in data tables. These thermocouples were linked to a custom-designed I/O system that instantaneously provided temperature data to a National Instruments ("NI") SCB-68 shielded Input/Output connector block with cold-junction temperature compensation sensor. SCB-68 output was connected to an IBM M50 PC running on Windows XP Service Pack 3 within which an NI PCI-6011E Data Acquisition ("DAQ") board was driven by NI DAQ software v. 7.42. NI DAQ output was output directly to a custom programmed Excel spreadsheet). This procedure was repeated for all three NRTE products, and cooked in all eight ovens.



Fgure 1. A "Hedgehog" thermocouple array with the thermocouples placed within food components. Tray of NRTE product is placed into the rigid foam tray holder to reduce heat loss during temperature measurement. The thermocouples may be raised or lowered with the large handle.

RESULTS AND DISCUSSION

Microwave output power

Table II compares the manufacturers' declared microwave power to that measured using the IEC705 procedure, and shows that all eight microwave ovens were significantly lower in "IEC" power than the declared wattages. These measured power outputs ranged from 70.9% to 87.8% of the manufacturer's declared power, and that indicates that the manufacturers' declared microwave power is unreliable as a cooking guideline and must be tested in any program involving the use of microwave ovens.

Having tested many microwave ovens in the past 30 plus years, this discrepancy has been shown to be true [Schiffmann,

Table II. Manufacturers' vs. IEC-measured microwave power.			
Manufacturer	Advertized Microwave Power (watts)	IEC 705 Microwave Power* (watts)	% IEC vs. Manufacturer's Power
GE	1100	899	81.7
LG	1200	851	70.9
Frigidaire	1100	842	76.5
Kenmore #1	1200	899	74.9
Sharp	1100	843	76.6
Kenmore #2	1200	897	74.8
Magic Chef	1100	966	87.8
Emerson	1100	929	84.5
* Average of three measurements made on different days.			

Table III. Influence of pre-warming microwave ovens				
Manufacturer	IEC 705* Microwave Power: Cold (watts)	IEC 705* Microwave Power: Warm (watts)	T Test Comparison Cold vs. Warm	Significance @ 95% confidence level
GE	899	914	0.796	NS
LG	851	860	0.669	NS
Frigidaire	842	858	0.704	NS
Kenmore #1	899	930	0.032	SIG
Sharp	843	842	0.425	NS
Kenmore #2	897	881	0.283	NS
Magic Chef	966	920	0.572	NS
Emerson	929	938	0.718	NS
* Average of three measurements made on different days.				

2005]. Table III shows that pre-warming of these ovens had little effect upon the IEC measured power; only one microwave oven, the Kenmore #1, showed a significant change at the 95% confidence level, in which case the warmed oven power was higher than the cold IEC power.

Cooking in Standard Microwave Ovens

Each one of the products is analyzed individually.

Product #1 Chicken Breast: The temperature measurement data from these tests is shown in Table IV. As noted earlier, all tests were run three times in each microwave oven and on different days. Since the manufacturer's cooking directions stated 160 °F as the minimum safe temperature, any temperature below this was given a "Fail" score, and this is indicated in Table IV by the blue boxes. A summary of these Fail temperatures is shown in the column "UNSAFE TEMPERATURES" that lists the number of under-temperatures in that test. In this case, Product # 1 was successfully cooked 100%, of the time, i.e. no unsafe temperatures, by only the Frigidaire oven. There was at least one temperature below the required 160 °F minimum in all the other ovens, and GE, LG, SHARP and both Kenmore ovens failed in every test. Most failures to reach 160 °F occurred in the Chicken Breast,

Table IV. Product # 1: Chicken Breast: product temperatures after following cooking instructions.

AVERAGE TEMPERATURE (˚F) @ EACH THERMOCOUPLE LOCATION								
THERMO-COUPLE	1 CHICKEN EDGE	2 CHICKEN CENTER	3 GRAVY EDGE	4 GRAVY EDGE	5 MASH POT EDGE	6 MASH POT CENTER	7 MASH POT EDGE	PASS TEMPERATURE = 160 ˚F
MICROWAVE OVEN								UNSAFE TEMPERATURES
GE	127	139	181	195	173	189	189	2
"	168	134	168	191	177	177	142	2
"	133	120	193	195	188	156	194	3
LG	125	173	187	182	196	181	198	1
"	136	143	183	191	195	187	191	2
"	159	192	203	182	186	173	188	1
FRIGIDAIRE	194	194	190	197	193	163	198	0
"	183	192	198	200	198	188	193	0
"	189	195	207	195	193	195	196	0
KENMORE #1	118	97	165	184	178	190	109	3
"	199	161	201	174	182	131	193	1
"	123	109	194	185	188	96	191	3
SHARP	140	121	176	198	163	124	192	3
"	115	96	197	189	174	185	88	3
KENMORE #2	169	169	204	198	159	175	193	1
"	159	146	197	195	189	193	179	2
"	144	188	179	200	190	178	191	1
MAGIC CHEF	170	156	198	200	193	193	193	1
"	204	199	204	189	191	169	195	0
"	189	170	201	200	194	201	197	0
EMERSON	189	203	196	193	197	165	189	0
"	152	141	174	204	184	198	196	2
"	140	151	178	200	195	196	194	2

with some also in the Mashed Potatoes. No unsafe temperatures were measured in the gravy, possibly due to the presence of salt, which significantly influences the heating rate.

Product # 2: Beef. The results of these tests are shown in Table V, while no oven produced safe temperatures in every test, GE, Sharp, Emerson and both Kenmore ovens failed in everyone. Numerous unsafe

Table V. Product # 2: Beef: product temperatures after following cooking instructions.

	AVERAGE TEMPERATURE (˚F) @ EACH THERMOCOUPLE LOCATION							
THERMO COUPLE:	1 BEEF@EDGE CENTER	2 BEEF@CTR CENTER	3 BEEF@EDGE CENTER	4 SAUCE EDGE	5 SAUCE EDGE	6 VEGETABLE EDGE	7 VEGETBLE EDGE	PASS TEMPERATURE = 160 ˚F
MICROWAVE OVEN								UNSAFE TEMPERATURES
GE	142	135	186	185	169	193	194	2
“	189	107	170	93	123	191	187	3
“	144	131	198	95	141	185	184	4
LG	160	193	195	162	183	183	184	0
“	190	134	165	74	125	193	193	3
“	186	186	147	109	147	187	189	3
FRIGIDAIRE	150	135	181	191	169	194	182	2
“	190	186	203	162	183	196	190	0
“	174	149	196	138	161	198	185	2
KENMORE #1	136	131	165	160	152	173	174	3
“	169	126	136	188	150	187	175	3
“	169	113	176	104	131	187	182	3
SHARP	144	172	187	166	175	183	188	1
“	159	196	180	102	159	184	192	3
“	157	77	155	66	100	191	187	5
KENMORE #2	187	102	144	112	119	183	183	4
“	185	135	161	95	130	190	180	3
“	200	183	191	155	176	182	191	1
MAGIC CHEF	180	198	150	185	178	186	192	1
“	165	169	202	181	184	193	186	0
“	199	197	201	199	199	177	180	0
EMERSON	188	186	157	97	147	187	193	3
“	143	203	181	164	183	188	195	1
“	157	138	191	145	158	197	181	4

temperatures were recorded in both the beef and the sauce. The very low temperatures in the center of the beef were likely due to the short depth of microwave-penetration in this food.

Interestingly, all the temperatures in the vegetable were considerably higher than the required minimum safe temperature, and often higher than the temperatures seen in the other food components, indicating the

Table VI. Product # 3: Turkey Breast: product temperatures after following cooking instructions.

AVERAGE TEMPERATURE (˚F) @ EACH THERMOCOUPLE LOCATION								
THERMO COUPLE:	1 MASH POT EDGE	2 MASH POT CENTER	3 MASH POT EDGE	4 STUFFING EDGE	5 STUFFING CENTER	6 TURKEY CENTER	7 TURKEY EDGE	PASS TEMPERATURE = 160 ˚F
MICROWAVE OVEN								UNSAFE TEMPERATURES
GE	193	203	148	199	201	158	199	2
“	203	177	160	189	202	159	198	1
“	203	148	141	200	204	178	202	2
LG	197	164	183	195	199	118	199	1
“	190	156	183	199	193	202	195	1
“	203	175	149	205	204	200	190	1
FRIGIDAIRE	200	208	203	204	202	207	200	0
“	205	200	205	205	203	201	201	0
“	194	203	202	201	201	189	202	0
KENMORE #1	200	208	203	204	202	207	200	0
“	173	169	198	176	145	194	186	1
“	204	163	164	200	198	143	195	1
SHARP	195	166	125	160	199	198	148	2
“	164	182	178	198	163	192	150	1
“	204	147	183	194	199	172	200	1
KENMORE #2	185	205	197	195	201	181	200	0
“	166	191	202	196	190	132	196	1
“	180	147	201	159	199	125	194	3
MAGIC CHEF	202	146	180	202	198	139	198	2
“	205	200	205	199	205	200	185	0
“	201	184	201	198	202	198	201	0
EMERSON	204	199	200	200	204	202	203	0
“	207	205	204	207	202	189	201	0
“	187	200	151	198	195	145	184	2

very good microwave receptivity of these vegetables.

Product # 3: Turkey Breast. The results of the temperature tests are seen in Table VI. Here, unsafe temperatures were seen in every entrée component: turkey breast, mashed potatoes and stuffing, indicating the need for the manufacturer to reexamine the entire product. As in Product # 1, only the Frigidaire oven produced safe temperatures in each sample. The GE, LG and Sharp ovens all had at least one unsafe temperature in each of the three replicate tests.

Despite carefully following of the manufacturer's cooking instructions, the large number of tests performed in eight new 1100-watt and 1200-watt microwave ovens failed to produce safe cooking conditions for each food product in each oven. While taking great efforts to store, handle, cook and measure temperatures as carefully and reproducibly as possible, and running the tests in triplicate for each product in each microwave oven, none of the eight ovens was able to cook all of the products to a completely safe minimum temperature every time. These findings are summarized in Table VII, which shows the percentage of failure encountered in each oven, The best performance was seen in the Frigidaire microwave oven, which cooked two of the three products to the required minimum temperature every time, but then failed to achieve only safe temperatures in two of the three samples of the third product. The Magic Chef microwave oven failed in one of three samples in every product. Two GE and Sharp ovens performed particularly poorly since every sample of every product had at least one unsafe temperature.

Based upon this, it is must be concluded that the cooking of NRTE frozen products in standard microwave ovens does not meet the criteria for food safety of reaching at least the minimum safe cooked temperature of 160 °F in every component every time.

This means that consumers cannot be guaranteed safe cooking of these NRTE products in every microwave oven. Since it is important that microwave cooking guarantees safe temperatures for each NRTE product, and that the standard microwave ovens in the marketplace and in consumers' homes are not likely to change, rather than removing these products from the marketplace, there are two possible approaches to achieve 100% food safety for NRTE products generally:

(1) Improve the cooking performance of each NRTE product.

Manufacturers of NRTE products need to reexamine their products' contents, design and heating instructions to improve the cooking performance across the vast number of microwave ovens being used by consumers. Given the dramatic difference in the size, wattage and other performance attributes of these ovens; and given the reluctance, and sometimes inability, of consumers to follow complicated instructions [IMPI, 2011], the likelihood of success of this approach is small.

(2) Improve the performance of microwave ovens.

Over the years, there have been many attempts to improve the cooking performance

Table VII. % Failure of eight conventional microwave ovens.

OVEN	PRODUCT # 1	PRODUCT # 2	PRODUCT # 3
GE	100	100	100
LG	100	67	100
Frigidaire	0	67	0
Kenmore #1	100	100	67
Sharp	100	100	100
Kenmore #2	100	100	67
Magic Chef	33	33	33
Emerson	67	100	33

% Failure = (# replicates that failed / total number of replicates) x 100.

Table VIII. Product # 1: Chicken Breast: product temperature after using TCP cooking code.

THERMO COUPLE:	1 CHICKEN EDGE	2 CHICKEN CENTER	3 GRAVY EDGE	4 GRAVY EDGE	5 MASH POT EDGE	6 MASH POT CENTER	7 MASH POT EDGE	PASS TEMPERA-TURE = 160 °F
TCP OVENS								UNSAFE TEMPERATURES
LG	206	203	209	208	204	205	201	0
"	190	161	205	211	182	200	200	0
"	209	182	196	206	198	198	194	0
KENMORE #1	209	202	204	214	205	205	178	0
"	211	211	213	204	206	205	202	0
"	211	201	213	210	202	203	201	0
KENMORE #2	199	208	207	211	205	207	197	0
"	210	210	205	212	200	196	203	0
"	210	210	210	220	208	207	199	0

of microwave ovens. One very intriguing approach is the development of "Smart" microwave ovens, as discussed in the Food Safety Forum at the 2011 IMPI Symposium #45. These ovens are controlled by internal computer logic to achieve optimum cooking results. This second approach is addressed by testing three smart ovens already described in the section Materials and Methods.

Cooking in Smart Ovens

The results of all the tests on the three products are shown in Tables VIII, IX and X. Note that there are no blue boxes in any Table, indicating that all the temperatures at every location, in every sample and for every oven exceeded at the required minimum temperature of 160 ºF.

A statistical comparison of the data on the performance of Standard vs. Smart ovens is summarized in Tables XI, XII, XIII. All the data, from each test, was analyzed to determine the Mean, Standard Deviation and Range of temperatures from highest to lowest in each sample. A visual inspection of the smart oven data indicates that the Mean temperatures are generally higher, Standard Deviation and the Range of temperatures are smaller in the TCP ovens. Simple T Tests of all the data and confirmed by ANOVA analysis, demonstrates that this is not only true, but the P values indicate that there is an "extremely significant difference in these aspects favoring the Smart (TCP) over the Standard microwave ovens. A smaller Standard Deviation and Temperature Range of the TCP samples means that there is less likelihood of extreme differences in temperatures in the food, i.e. areas that are hot while others are cool.

The higher Mean temperatures favor food safety as they are more likely to exceed the minimum required temperatures.

FINAL REMARKS

This research was conducted to determine whether by microwaving Not-Ready-to-Eat (NRTE) products it is possible to guarantee their ability to reach the safe temperatures, throughout the products, required to destroy any residual microorganisms that might cause foodborne illness. NRTE products are not fully thermally processed but require that consumers finish cooking them to the required safe temperatures. But, the home kitchen is

Table IX. Product # 2: Beef: product temperature after using TCP cooking code.

AVERAGE TEMPERATURE (˚F) @ EACH THERMOCOUPLE LOCATION							
THERMO COUPLE:	1 BEEF@EDGE CENTER	2 BEEF@CTR CENTER	3 BEEF@EDGE CENTER	4 SAUCE EDGE	5 SAUCE EDGE	6 VEGETABLE EDGE	7 VEGETBLE EDGE	PASS TEM-PERATURE = 160 ˚F
TCP OVENS							UNSAFE TEMPERATU-RES
LG	191	204	207	192	205	191	188	0
“	208	208	208	204	201	176	194	0
“	180	207	193	208	201	195	193	0
KENMORE #1	209	208	205	206	209	178	174	0
“	165	208	209	206	204	179	187	0
“	208	206	203	204	204	178	189	0
KENMORE #2	162	206	193	199	199	172	188	0
“	205	196	207	201	211	199	183	0
“	209	187	206	204	198	175	187	0

Table X. Product # 3: Turkey Breast: product temperature after using TCP cooking code.

AVERAGE TEMPERATURE (˚F) @ EACH THERMOCOUPLE LOCATION:								
THERMO COUPLE:	1 MASH POT EDGE	2 MASH POT CENTER	3 MASH POT EDGE	4 STUFFING EDGE	5 STUFFING CENTER	6 TURKEY CENTER	7 TURKEY EDGE	PASS TEM-PERATURE = 160 ˚F
TCP OVENS								UNSAFE TEMPERA-TURES
LG	208	209	206	203	205	192	202	0
“	209	172	203	200	206	185	207	0
KENMORE #1	206	209	210	208	209	202	202	0
“	198	208	209	207	206	203	203	0
“	205	206	206	205	206	203	206	0
KENMORE #2	195	207	207	206	197	206	202	0
“	202	208	177	209	207	191	205	0
“	207	190	199	207	206	199	204	0

Table XI. Product # 1: Chicken Breast: Statistical evaluation of the temperature data.

MICROWAVE OVEN	T E M P E R A T U R E S				
	MEAN	STD DEV	Max.	Min.	Range
STD OVENS					
GE	170.4	26.7	196	125	71
“	165.3	20.3	193	131	62
“	168.4	31.9	198	120	78
LG	177.4	24.7	199	119	79
“	175.1	24.7	195	135	61
“	183.3	14.1	205	159	46
FRIGIDAIRE	189.9	12.1	201	150	52
“	193.1	6.1	202	182	19
“	195.7	5.5	208	189	19
KENMORE #1	148.7	39.3	191	97	94
“	177.3	24.9	203	128	75
“	155.1	43.6	195	96	99
SHARP	159.1	31.5	201	120	81
“	149.1	47.5	197	87	111
KENMORE #2	181.0	17.2	204	157	47
“	179.7	19.8	198	145	53
“	181.4	18.1	200	144	56
MAGIC CHEF	181.4	18.1	201	155	46
“	186.1	16.5	206	167	39
“	193.1	11.1	205	169	36
EMERSON	190.3	12.2	203	162	41
“	178.4	28.1	205	140	64
“	179.1	24.2	201	139	62
AVERAGE	176.5	22.5	201.2	141.2	60.0
TCP OVENS					
LG	205.1	2.7	211	200	12
“	192.7	16.9	212	161	51
“	197.6	8.7	209	181	28
KENMORE #1	202.4	11.5	217	167	50
“	207.4	4.2	213	199	14
“	205.9	5.2	214	200	14
KENMORE # 2	204.9	5.0	212	193	19
“	205.1	5.9	212	193	19
“	209.1	6.2	220	198	22
AVERAGE	203.4	7.4	213.4	188.0	25.3
P VALUE	<0.0001	0.0004	<0.0001	<0.0001	0.0003
	E X T R E M E L Y S I G N I F I C A N T				

Table XII. Product # 2: Beef: Statistical evaluation of the temperature data.

MICROWAVE OVEN	TEMPERATURES				
	MEAN	STD DEV	Max.	Min.	Range
STD OVENS					
GE	172.0	24.4	195.9	134.8	61.0
"	151.4	42.4	192.4	84.2	108.1
"	154.0	36.7	197.9	93.7	104.1
LG	180.0	13.9	195.3	160.1	35.2
"	153.4	44.9	195.0	72.0	123.0
"	164.4	30.9	196.3	108.0	88.3
FRIGIDAIRE	171.7	21.9	195.9	134.7	61.2
"	187.1	13.0	202.9	160.1	42.8
"	171.6	23.2	198.2	138.1	60.1
KENMORE #1	156.2	17.1	185.6	128.4	56.2
"	161.7	24.7	188.8	123.7	65.1
"	151.6	34.7	187.6	103.5	84.2
SHARP	173.7	15.4	192.7	143.3	49.3
"	167.6	32.5	196.8	97.1	99.7
"	133.3	51.6	191.1	65.4	125.7
KENMORE #2	147.1	36.9	198.6	100.7	97.9
"	153.8	35.3	194.5	92.3	102.2
"	182.8	14.4	200.5	154.4	46.1
MAGIC CHEF	181.3	15.4	198.5	149.5	49.0
"	182.8	12.9	202.2	164.3	37.9
"	193.3	10.3	201.0	176.6	24.4
EMERSON	165.2	34.8	196.1	90.8	105.3
"	179.6	20.2	203.7	141.5	62.2
"	166.7	22.9	201.3	138.0	63.3
AVERAGE	166.8	26.3	196.2	123.2	73.0
TCP OVENS					
LG	196.7	8.2	206.8	186.3	20.6
"	199.8	11.9	208.3	174.9	33.4
"	196.6	9.6	208.3	179.5	28.7
KENMORE # 1	198.5	15.3	209.4	172.6	36.9
"	194.0	17.2	208.6	156.6	52.0
"	198.9	11.2	208.4	174.6	33.7
KENMORE # 2	188.4	16.0	206.0	161.0	45.0
"	200.2	9.3	211.1	180.8	30.3
"	195.1	12.5	209.2	174.4	34.8
AVERAGE	196.5	12.4	208.5	173.4	35.0
P VALUE	>0-0001	0.0013	>0.0001	>0.0001	>0.0001
	EXTREMELY SIGNIFICANT				

Table XIII. Product # 3: Turkey Breast: Statistical evaluation of the temperature data.

MICROWAVE OVEN	TEMPERATURES				
	MEAN	STD DEV	Max.	Min.	Range
STD OVENS					
GE	185.9	23.1	203.3	146.9	56.4
"	184.0	19.1	203.2	157.9	45.3
"	182.2	27.5	204.5	139.8	64.7
LG	179.4	29.9	200.9	117.6	83.3
"	188.1	15.6	202.4	154.5	47.9
"	189.4	20.7	205.1	147.2	58.0
FRIGIDAIRE	203.6	3.0	208.1	199.5	8.6
"	202.9	2.1	205.3	199.4	6.0
"	198.9	5.2	203.2	187.8	15.4
"	203.6	3.0	208.1	199.5	8.6
KENMORE #1	177.3	17.9	201.0	135.0	66.1
"	181.0	24.1	204.6	141.1	63.4
"	170.2	28.5	199.6	124.7	74.9
SHARP	175.3	17.3	198.8	128.2	70.7
"	185.6	20.3	204.5	140.4	64.0
"	194.7	8.6	204.7	179.8	24.8
KENMORE #2	182.0	24.7	202.9	130.7	72.2
"	172.2	29.3	203.5	123.0	80.4
"	180.5	27.3	202.3	137.6	64.8
MAGIC CHEF	199.9	7.2	205.7	182.4	23.3
"	197.9	6.2	203.7	182.9	20.8
"	201.7	2.0	204.8	199.0	5.8
EMERSON	202.0	6.1	207.1	187.4	19.7
"	180.1	22.7	200.5	139.9	60.6
"	184.8	25.9	205.0	129.5	75.4
AVERAGE	188.1	16.7	203.7	156.9	46.9
TCP 0VENS					
LG	203.6	5.5	208.9	190.9	17.9
"	197.3	13.8	209.1	170.7	38.4
KENMORE # 1	206.5	3.4	210.3	200.4	9.9
"	205.2	3.8	209.3	196.1	13.2
"	205.3	1.2	207.1	201.2	6.0
KENMORE # 2	202.8	5.1	207.3	193.7	13.6
"	199.9	11.7	210.0	172.6	37.5
"	201.9	6.2	207.6	190.0	17.6
AVERAGE	202.8	6.3	208.7	189.5	19.2
P VALUE	0.0006	0.0075	0.000003	0.0032	0.0075
	EXTREMELY SIGNIFICANT				

a totally uncontrolled environment and consumers may not be able to fulfill the requirements for many reasons: not knowing their ovens' microwave powers; often being impatient and following instructions imperfectly; many do not have an adequate kitchen thermometer, and if they do, not knowing how to use it; and more. Of course, every chef would say that proper cooking belongs in the hands of the cook. However, this really applies to conventional cooking where the cook normally follows a recipe or a well-known cooking procedure of at least several minutes. But using a microwave oven is in many ways similar to using the early Kodak cameras: one only needed to push a button and the camera did the rest. Similarly, these NRTE products tell the cook to set the cooking time suggested by the manufacturer and push a button to start the cooking process in the microwave oven. While it is usually suggested to adjust the cooking time to match the particular oven's power, and to use a kitchen thermometer to check that the required temperatures have been achieved, these steps may not occur, or occur inadequately, for the reasons stated above. By using exacting temperature measurement techniques and handling procedures in these tests, it has been demonstrated that the cooking instructions provided by the manufacturer for standard microwave ovens are often inadequate to reach the required safe temperatures. This may is be primarily due to the lack of opportunity for conductive heat transfer to occur. This is especially important in cases where the food component is large in volume and mass, such as a chicken breast; in these tests it was difficult to heat the interior with microwaves because of the short penetration depth into the chicken and the lack of sufficient standing time to allow conductive heat transfer to occur. A good illustration of this is how one is instructed to cook a large piece of meat such as a 4 inch (10 cm) diameter beef roast in a microwave oven. Very little or no microwave energy will reach the center of the beef because the penetration depth is less than 1 cm, and so the cook is instructed to microwave the beef to an internal temperature of approximately 115 - 120 °F (46 - 49 ºC), removing it from the microwave oven, wrapping it in aluminum foil, and allowing it to stand for 15 or 20 min. while thermal conductivity raises the interior temperature to 125 - 135° F (52 - 57ºC). But, with the short microwave cooking and standing times suggested by the manufacturers there is simply not enough time for this conductive heat transfer to occur. It is not a fault of the microwave oven, but rather that the recommended cooking times and procedures are inadequate to produce the required result. A major strength of the smart oven technology employed in these tests is that it takes the control of the cooking procedure out of the hands of the consumer and replaces it with digitized computer control utilizing lower as well as full power levels, also employing rest times in the cooking cycle, thereby allowing conductive heat transfer to occur.

The results found in this paper are not a condemnation of microwave ovens but rather define two major problems:

a) Microwave power output claimed by the manufacturers is often much higher than the actual IEC measured power output. This is a significant problem since it misleads consumers into thinking that their ovens are much more powerful than they actually are, and therefore they follow cooking times that are probably too short.

b) The whole concept of not fully thermally processing foods to be cooked by consumers is seriously flawed. What these temperature profiles indicate is that by simply following the heating instructions provided by the manufacturer, it is quite possible that the food will not reach safe temperatures and therefore can be considered a serious safety issue.

CONCLUSION

Microwave oven manufacturers use what is thought to be an average value for a particular model of oven based upon testing a representative sample of their production. However, as demonstrated in this document, the output powers supplied by the manufacturers for these ovens are considerably higher than those measured by the IEC 705 procedure; these IEC values were only 70.9% to 87.8% of the claimed values, i.e. lower (note they were never higher). This is of great concern because the average consumer is unable to run this procedure or anything similar to it, and so must rely on the manufacturers' numbers. This situation can result in the consumer not cooking the NRTE products long enough, since the food processors cooking instructions are based upon 1100 or 1200-watt ovens.

The inadequate microwave cooking of Not-Ready-to-Eat products is shown by the distribution of temperatures in the components of each of the three products, highlighting those that are less than the required safe cooking temperatures. This demonstrates that even when the cooking instructions provided by the food processor are followed exactly, there are still places within components that may not have reached the required safe temperatures. The results show the failure rate in each oven; only one of the eight conventional ovens cooked one of the products successfully every time, and all three products failed each time to reach the minimum safe temperatures in three of the ovens. Whereas, the smart ovens reached the required safe temperatures in every test. It was not within the scope of these tests to determine the reason for these failures. It remains unknown whether using the actual ovens' powers to adjust the cooking times would have been sufficient to provide the minimum safe temperatures every time. However, it is important that such a study be done and the results reported to consumers as well as food processors.

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