POSSIBLE HAZARDS IN HEATING MICROWAVABLE PRODUCTS

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It was at a conference in the Fall of 1987 in Chicago sponsored by the Microwave Oven Cookware Division of the Society of the Plastics Industry that I heard Lew Erwin of Kraft first bring up the topic of the real hazards of microwave ovens, namely, problems associated with overheating and peculiar heating effects upon foods. Prior to that, I had published a paper in Microwave World (1) discussing problems in the performance of microwavable popcorn products, which included fires. I had also written a letter to the editor of Microwave World discussing questions relating to the use of microwave susceptors in terms of their capacity to overheat products and perhaps cause hazardous conditions as a result. There had also been some indication in the medical literature (2) (3) of problems associated with microwavable foods, mainly, steam burns caused by steam pressure from popcorn packages, and the scalding of infants due to excessively hot baby formula. It is the purpose of my paper to look at some of the possible hazardous conditions which may result when heating food in microwave ovens, and try to find an explanation for their cause. Where possible, I shall also attempt to recommend procedures that can be used to avoid or overcome such problems.

The possible problems that can occur with foods in microwave ovens can be categorized as follows:

1. Overheating
2. Steam generation
3. Boil over
4. Volcano effects
5. Oil heating
6. Fires

I. Overheating

Probably the most common problem occurring in a microwave oven relates to overheating of products. For the most part this manifests itself in excessive heating, possibly causing drying out of sauces or some charring of casserole and similar events. These, in themselves, are not hazardous, but rather have a deleterious effect upon the quality of the food product. Those problems that lead to hazard are generally a result of overheating that is hidden from the consumer and can result in injury to the unwary person eating the food. As background to this, we must first consider the fact that microwaves are not a form of heat, but rather are a form of energy, which may manifest heat due to their interaction with materials. As a result of this, unusually high temperatures may be achieved in microwave ovens. For example, one can, in a home microwave oven, melt sand or glass at over 1000 F. A second concept which must be kept in mind, is the fact

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that microwave energy presents a bulk heating phenomenon, in which both the surface and some or all of the interior of the product is heated simultaneously. Coupled with this is the unusual temperature profile that is often seen in a microwave oven. For example, it is not uncommon for the surface temperature to be significantly lower than the temperature in the interior of the product. This lowered surface temperature is usually due to the fact that the air in a microwave oven is cold and, therefore, the surface of the product is losing heat to the air. At the same time, any evaporation that may be occurring from the surface may be causing evaporative cooling.

It is also possible that unusual hot spots may occur within a food product as the result of the higher field densities which may occur on the interior and, in fact, be localized within the product. Factors which influence the existence of such hot spots or hot zones are the shape, mass, density, size of the product, as well as its dielectric properties, and how they effect the penetration depth of microwaves into the interior. In an outstanding paper in the Journal of Microwave Power (4), Ohlsson and Risman showed thermographs indicating heating concentration at the center of spheres and cylinders for diameters of 20-60mm and 18-35mm respectively.

An example of such unusual temperature profile effects can be seen when comparing the profiles of roast beef, which may show very high temperatures near the surface, but very low temperatures in the interior, at which point it is quite likely there is no microwave energy at all; and, those temperatures achieved in baking a potato, in which the highest temperatures may, in fact, be at the center of the potato, and could, in fact. cause charring of the center, while the surface maintains a perfectly good quality.

A good example of a problem that can arise as a result of overheating is that encountered in baby food. Small jars of baby food can become deceptively hot in the center, while the surface remains cool to the touch. Baby food is generally a product with a high solids content, and as a result, a quite low specific heat. The combination of this low specific heat, the penetration depth of the microwaves into the baby food, and the cylindrical nature of the container lend themselves to a situation in which high temperatures can be seen within the food, while the glass jar surface remains cool due to the above mentioned heat losses. Some experimental data from our laboratory is shown in Table 1.

<u>Baby Food</u>

	Temperature (F)	
Time (Min)	Surface	Highest
0.5	96	177
1.0	103	223

Table 1: Temperatures measured in baby food jars, at the surface of the glass and the highest temperatures measured in the interior

As can be seen, the unsuspecting mother, feeling the surface of the jar might think the food to be at a quite comfortable temperature, and yet, unless she tastes it, the infant could be scalded quite severely by unusually high temperatures in the product. The extraordinarily short times in which such temperatures are achieved is also of concern since it indicates that small changes in the heating time can cause unusually high temperatures. Perhaps, it would be best to recommend against the use of microwave ovens for the heating of baby food. Certainly, there should be warnings on the label that if heating in a microwave oven, the food should be tested and that the heating should be done with great care because of the possibility of overheating. If one were to try to attack this problem from another point of view, it might be that the shape of the container could be changed to be more of a bowl shape, thereby, perhaps reducing some of the focused hot spots that seem to occur.

II. Steam Pressure

With the rapid heating and high temperature in moist foods, there is potential for steam pressure build up in cases in which the container is closed. A case in point would be that encountered in microwave popcorn bags. In our earlier mentioned research work on microwave popcorn, one of the findings we noted was the fact that while the popcorn bags are meant to vent due to the build up of temperature and steam pressure, sometimes this does not occur. As a result, it is quite possible that the consumer opening the popcorn bag could encounter very high temperature steam. Such a case was described in The New England Journal of Medicine (3) in which a child's eyelids were scalded by steam from microwave popcorn. An obvious solution to this is to insure that the sealing system would be foolproof in its venting ability.

Other possible problems from steam can be caused by unusually tight containers or lids, or plastic wrap. One popular microwave cookbook recommends tightly wrapping plastic wrap around and over food products while heating in the microwave oven. There are cautions that the plastic wrap should be pierced prior to removal, however, as we all know, consumers don't always follow directions and the build up of steam within the product could lead to some burns and scalding. Another possible hazard can occur in cases in which the consumer fails to remove the lid of a product placed in a microwave oven. Some years ago, in our laboratory, we had the task of testing a product in a jar that was being prepared for distribution as a microwavable product. In one of the tests we ran, related to determining what happens if the consumer neglects to remove the cap from the jar when heating it in a microwave oven, we learned that these caps will automatically vent at approximately eleven or twelve pounds of pressure, so explosion of the glass jar is avoided. However, that product is still under high pressure and should the consumer attempt to remove the cap, the product will literally explode out of the jar. Also, if the consumer should recognize what has happened and place the jar under cold running water an explosion may occur.

Obviously, caution should be placed upon the jar to insure that the cap is removed prior to heating.

Ill. Boil Over

One of the most common occurrences of heating problems within microwave ovens is the boiling over of liquids such as coffee, or water. Two scenarios are generally seen here: in the first, the consumer heats the cup of coffee and when opening the microwave oven sees the quiescent liquid which, upon being handled, erupts forcing boiling hot contents over the sides of the cup and possibly onto the consumer's hand. In the second, when the consumer has heated the water in the microwave oven, and adds a teaspoonful of instant coffee to the apparently quiescent water, an eruption of liquid occurs all over the oven. The causes of this are quite fascinating from the point of view of physics and bubble mechanics.

Bubbles have the property of wanting to grow. They need to constantly relieve the internal pressure and equilibrate it with the outside of the bubble. A second property of bubbles is that they cannot spontaneously form. The smaller a bubble is, the higher its internal pressure so that an infinitely small bubble would have an infinitely high pressure. In other words, in order for a bubble to appear, it has to have been there to begin with. Let's examine for a moment what happens when we boil water upon a stove: the water that is placed in the pot generally has a good deal of dissolved air in it, and usually forms microscopic bubbles along the wall of the pot. When the water is heated to the point of boiling, these microscopic bubbles begin to grow due to an increase of the internal pressure within the bubble and dissolution of dissolved gas into the bubble. Consequently, we see bubbles form along the bottom and sides of the pot, and as they reach critical volume, they become buoyant, leave the walls of the pot, and as they rise begin to expand since the pressure around them is decreasing, and vigorous boiling occurs. During their rise or even along the sides, bubbles may scavenge upon one another as a way of growing, and so, coalescence is a very frequent occurrence.

Now let us examine what happens to the water when it is boiled inside a microwave oven. In this case, again, the water has its dissolved air, but the difference is that when it is heated in the microwave oven, the cup in which it's heated remains relatively cool since it is losing heat to the surrounding air. and heating may, as a result, be far more intense in the interior of the water than it is along the side walls and the bottom, which is losing its heat from contact with the bottom of the oven. Consequently. it is quite possible that high temperatures, higher than normal boiling temperatures, may occur within the water, causing superheating of the liquid. Now, if the consumer reaches in to touch the cup, bubbles, which are along the side and bottom of the cup have not reached their critical buoyancy, may be dislodged by the movement of the cup, and rapidly rise to meet the superheated liquid and therefore expand explosively. In the second scenario, the superheated liquid is now caused to erupt when the powdered coffee with its large amount of air adhering to its surface or its pore structure, is added.

An obvious solution to the coffee problem is to advise the consumer to add the coffee to the cool water prior to heating in the microwave oven. In heating a plain liquid, one good solution is to advise the consumer to place a spoon in the cup of the liquid, thereby providing a surface upon which bubbles can grow and become buoyant at their normal temperatures in the interior of the liquid. It has also been suggested that special containers, could be designed to make it easier for bubbles to grow and prevent super heating of liquids.

Another way in which boil over can occur is in such things as hot cereals, in which case, the high viscosity, combined with surface tension of the product allows for large bubbles to develop within the liquid, thereby causing it to expand in volume sufficiently to boil over the sides of the container. As a person who enjoys the heating of hot cereals during the winter time, I generally don't use my microwave oven. However, if I am required to, I found the easiest solution is to place the hot cereal in a container at least twice its volume and also to use a medium power setting, rather than a high power setting. In that case, we see the expansion and contraction of the cereal as the microwave oven goes through its pulse cycle. This phenomenon of superheating has been documented in two recent editions of Microwave World. In the first case(s), Dr. Charles Buffler of General Foods, reported upon tests run in his laboratory in which temperatures of approximately 220 F were encountered in the liquid. And in a letter to the editor in the subsequent issue (6), I indicated that in our own laboratory we had measured temperatures considerably higher at local points within the water, in some cases, rising to as much as 240 F.

IV. Volcanoes effects

There is a distinction between what I term volcano effects and boil over in that volcanoes are a result largely of the existence of particulates within the food product which cause overheating to occur. This can be seen in such things as chili and beef stew which are heated in a microwave oven. What may occur is that very high temperatures are reached and the presence of large particulates combined with certain particle geometries leads to a situation in which a very high pressure may build up with the only relief to lift the contents out of the container and may cause them to be violently splattered about the microwave oven, similar the kind of thing one might see from a volcano. Cylindrical container shapes are particularly a problem in this case and should be avoided when producing products with high particulate content. At this point I am not certain whether anyone has successfully correlated particle size and viscosity of the surrounding liquid with the propensity to cause the volcano effect, although I do believe that such may in fact be possible to predict. The best way to avoid this effect is to simply avoid the use of cylindrical containers and use sloping wall containers as can be seen in products such as Lunch Buckets. These also employ vented lids.

From a formulation point of view probably the only thing that can be done successfully would be to modify the particulate size to maintain relatively small particulates within the product. Of course, this is not always possible, as for example, one might see in products such as chili. It may also be that a radical change in container geometry utilizing a shallow tray rather than a jar would be useful. Another possibility would be to utilize a jar in the shape of a small bundt pan (with a raised center).

IV. Oil Heating

The heating of oils in microwave ovens was a subject of controversy in the past year because of the recommendation in a cookbook that deep fat frying can be done in a microwave oven. This is something that microwave oven manufacturers had recommended against for years, and continue to do so. As a result of the controversy that was caused, we, in our laboratory, chose to examine the question by determining whether or not the heating of oil, and the deep fat frying of food products was the safe thing to do. This work was reported upon in an article in Microwave World (7). Essentially, our work tried to determine, first how hot oil can become in a microwave oven, second, how effective deep fat frying is, and third, whether or not deep fat frying is hazardous to the consumer.

To answer the first question, we heated a sample of corn oil in a 650 watt microwave oven. The temperature rise was measured utilizing a fluoroptic thermometer, and the temperatures achieved in a microwave oven were quite high, and what is particularly disturbing is that they continue to rise after reaching temperatures close to 500 F. There is some question as to whether or not this could approach the flash point (that is the point of spontaneous combustion of the oil) which is difficult to answer and has largely to do with the condition of the oil in terms of its free fatty acid content. Needless to say, however, these temperatures are quite high, and ignition could occur if the fat had been used quite a good deal and was not in condition.

On the question of the effectiveness of deep fat frying, we attempted to follow several recipes in the cookbook as well as trying potatoes, and found that, in general, the problem was that the addition of these wet food products caused a significant decline in temperatures and that recovery time back up to frying temperature was extraordinarily long, as much as 15 minutes.

We also found that the quality of the food products was questionable and as batch after batch was fried because of the sharp drop in temperature and difficulty of reheating the oil back up to temperature, so the products kept getting lighter and lighter.

As to the question of hazardous conditions, we felt that it did, in fact, offer a significant hazard since adding these wet foods such as potatoes and vegetables into the oil within the confined space of the microwave oven could cause boil over and spattering of the hot oil content onto the hands of the consumer. There was also the question of what one would do with the oil at approximately the temperature of 400 F after frying was done. Certainly, a consumer should never attempt to move oil at high temperature out of an oven. Then there is the question of what one does with that hot oil having removed it, and in general our feeling was that the entire process is much too hazardous.

IV. Fires

There have been numerous reports from consumers of fires within microwave ovens, and these have often occurred with consumer products. We shall examine a number of potential sources for such fires.

A. Popcorn

There have been quite a number of reports of microwave fires when preparing popcorn, and yet the causes of such fires are rather obscure. Certainly, popcorn itself presents an unusual load situation to a microwave oven. It is a rather poor absorber of microwave energy, and that is combined with a very low mass so that the coupling efficiency into the microwave popcorn is quite low. Perhaps the presence of the oil is helpful in causing it to pop, however, popcorn will pop without the presence of oil. Once the popcorn begins to pop, the number of unpopped kernels is decreasing, and therefore, the load to be popped gets smaller and smaller, while the volume of popped kernels gets larger and larger. One could look upon these popped kernels as representing a good thermal insulator in an enclosed environment, and also presenting a larger and larger target to the microwave energy which will effectively couple into the popcorn. In our earlier work on microwave popcorn above, we found that it was possible to achieve charring of popcorn within as little as 30 seconds to a minute over the proper popping time. This charring is most likely due to desiccation of the popped kernels and then continued heating by the microwave energy. While I have seen no published data on the dielectric properties of popped corn, one could speculate that it should resemble cellulosic materials which show the unusual phenomenon of rapid absorption of microwave energy when they become quite dry and warm. A good example of this is fires which may occur during the drying of wood: when the wood has become excessively dry by the microwave or dielectric dryer a fire may effectively occur on the inside of the wood.

Counteracting the argument that the fire occurs in the popcorn is recent work done in our laboratory that indicated that severe overheating of a number of commercial microwave popcorn caused no fires whatsoever. In those tests, we ran samples for as much as a half an hour in a microwave oven, producing a shriveled black mass with a severely charred popcorn bag and yet no sign of ignition whatsoever. And yet ignition has been reported and may be due to some problem within the popcorn bag, for example the inclusion of small pieces of metal, or the use of an improper adhesive or a fault within the microwave oven, as for example, a stuck mode stirrer which could cause an extraordinary hot spot to occur within the microwave oven. There are other possible causes, some of which are currently under study at numerous companies.

B. Herb Drying

Some years ago we experienced the ignition of herbs during their drying and subsequently, in discussions with a number of home economists, we learned that that is not an uncommon problem. For example, we found that in the drying of herbs such as oregano and thyme, that spontaneous ignition might occur in thirty seconds. These results were found during work that was being done on determining the performance characteristics of microwave paper towels in microwave ovens, and following the directions recommended by a cookbook for drying herbs in which the herbs were placed between paper towels. We found that in approximately 50% of the tests, fires were started within the paper towels and when we traced this back, saw desiccation of the fiber of the stems was occurring, and this in turn caused arcing and flame. It is therefore, probably best to recommend to consumers that either they do this with great care or that they not do it at all in their microwave ovens. The latter probably being the preferable recommendation. There have been reports of arcing in other vegetables as well.

C. Twist ties

Probably there is no more spectacular demonstration of confined fireworks than heating of a Baggie twist tie or a pad of steel wool within a microwave oven. High electric fields are built up along the metal wires causing sparking and arcing that would be the delight of any child although it is best that we keep this information to ourselves and don't let children know about it because the temptations to do this sort of thing could lead to problems. In the case of the twist tie, these are usually covered with paper and while flame is seen, it is rather small. I have seen one documented case of a microwave oven interior being burned up completely in the heating of a sandwich in a bag that had a twist tie around it. There is no way of avoiding these things from occurring other than to strongly recommend that consumers never put these in microwave ovens.

D. Paper towels

Several years ago there was great interest when Proctor and Gamble entered the market with Bounty microwave paper towels. A great deal of work was done to determine whether or not paper towels represent a fire hazard within a microwave oven. In our own work, we learned that the stacking of numerous sheets of paper towel on the order of 12 or more sheets of paper towels could, in fact, lead to ignition of the towels, while, we were never able to get a single or a layer of two or three towels to ignite no matter how long we heated them short of damaging our ovens in those tests. Another interesting phenomenon which occurred was that if one placed a crumpled paper towel in a microwave oven, if the ball of paper towel was tight ignition could occur, whereas if it was loose no ignition occurred, which could be due either to the concentration of fuel during the heating, or to heat losses or heat concentration.

E. Arcing

There has been for some years some concern about the potential of causing a fire due to arcing by the use of aluminum trays in microwave ovens. Such arcing does on rare occasion occur, and we for some time studied the possibility of arcs causing fires in such things as paper towels and paper covers and the like. We were never able to achieve ignition, although we did find some charred spots in the paper. It is likely that the large mass of paper and temperature surrounding it and the lack of build up of fuel to cause the fire combined to prevent fires from occurring in that case.

Conclusions

In conclusion, we note that there are a number of potential hazards in food products for microwave ovens, and that some of these can be avoided by either changing the nature of the container, or the way the product is handled. Often, the only thing that can be done is to warn the consumer not to use the product improperly, but to take certain steps to either avoid the problem from occurring or if it is related to a product such as baby food, making the consumer aware of it and therefore preventing any hazard to the child. There are, however, those situations such as Baggie ties and the like, which in themselves simply occur and cannot be avoided if the consumer chooses to place the product in the microwave oven.

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