J. of Food Technology

J. Fd Technol. (1976) 11, 319–329
Aug (4):

BZ 466 Add Glaser JH

A review of microwaves for food processing

A. J. H. SALE

Summary

Ideas for the application of microwave heating to the processing of food are reviewed. A selection has been made of ideas for pasteurizing, sterilizing, defrosting, dehydrating, cooking and other applications that are described in the literature. Several are discussed to illustrate particular aspects and characteristics of microwave processing, and to try and show some reasons for the successes and failures.

Microwave heating on its own has led to few commercially successful processes; however, when combined with conventional sources of heat, microwave heating appears to have greater potential, and has led to several successful processes.

Introduction

The idea of heating by microwaves has been around for over thirty years and its potential use for heating foods has always been one of the applications that has been studied. The predominant development has been in the use of microwave ovens for cooking and reheating food in the domestic and catering situations. Equipment manufacturers' efforts to introduce microwave heating into the food processing industry have met with little success: although many ideas have been put forward, often involving the development of special equipment, the majority have been discarded in various stages. However, there are several successful microwave processes in use.

The purpose of this paper is to review a range of ideas for applying microwave heating to food processing, to illustrate particular aspects of microwave processing, and to try and show up some reasons for success and failure.

Microwave heating has characteristics that make it different from conventional heating and are relevant to reviewing the applications. These are set out in the Appendix, but the main ones are as follows. Microwaves generate heat within the food itself, no heat transfer medium is involved and, there is little reliance on heat conduction within the food itself so the temperature of the food can be raised very rapidly. Micro-

Author's address: Unilever Research, Colworth/Welwyn Laboratory, Colworth House, Sharnbrook, Bedford MK44 1LQ.

waves do not penetrate metal, so food cannot be heated in a can. In contrast microwaves pass through plastics, paper and glass so food sealed in these materials can be heated.

For the purpose of reviewing applications and ideas the subject may be rather arbitrarily divided in four main areas: heat preservation; change of state; cooking; others. The design of equipment will not be discussed.

Heat preservation

Heat preservation includes pasteurization, sterilization and blanching. In general the hope is that the short time of microwave heating compared to conventional heating will reduce the amount of heat damage to the food, and will cut down overcooking such as may occur in canning. However, the potential gain in quality may not be achieved unless cooling is also rapid. As there is no heat transfer medium the elimination of leaching during blancing is expected.

Pasteurizing

Bakery products provide an example of pasteurizing. Some experimental work on pasteurizing bread was published by Olsen (1965) and shortly afterwards a factory pilot plant was installed in England for extending the shelf life of cakes (Evans & Taylor, 1967). The problem being tackled was that between baking and wrapping, the cakes were inevitably contaminated by mould spores carried in the atmosphere. This contamination resulted in mould growth and spoilage of the cakes in a short time. One of the ways of inactivating mould spores is by heat, but to heat a wrapped cake by hot air would take an inordinately long time because the heat conduction through a foam structure is very poor. In contrast microwaves can heat such a structure easily.

Experiments on sponge cakes showed that the heating, and therefore temperature rise was reasonably even throughout, so the pasteurizing temperature could be reached without serious overheating. A microwave tunnel oven was installed, and then practical problems arose. Cakes were baked batchwise, the tunnel operated continuously, and the factory organization was such that cakes could not be left around for a long time to cool to room temperature after baking. So the cakes were fed into the tunnel at a wide range of temperatures, and emerged also at a wide range of temperatures, because it is the temperature rise that is constant. Consequently, to ensure that all cakes were pasteurized, many were overheated. Furthermore, when it came to pasteurizing filled or iced cakes, not only was there differential heating, but melting occurred. These problems, which could have been foreseen, led to the abandonment of the process.

Sterilizing

Sterilizing in the pack is an idea that has been around for a very long time. It is often suggested that the long heat treatment that is required in canning impairs the quality of the food; the long time results from the limitation of heat transfer internally, so that to achieve adequate heat treatment throughout, much of the food receives excessive treatment. By using microwaves for the heating, and plastic packs to let the microwaves through, very much more rapid heating is possible. So although the cooling stage may be slow the overall process time is shortened and the hope is that better quality may result. The concept has several problems. First it presupposes that the heating is even, but this is extraordinarily difficult to achieve. With uneven heating the temperature reached in the food differs from place to place. As it is necessary to ensure that the coolest part reaches a high enough temperature for a particular time, other parts of the food reach higher temperatures and are overtreated. This illustrates another characteristic of microwave heating: that there is no natural temperature limitation when heat is continually generated in the food, except, for example, when boiling is reached and the heat goes into vapourizing water. In contrast when using a heat transfer medium, the food cannot get hotter than the medium. A practical problem in microwave sterilizing is the need to maintain the integrity of the flexible plastic pack; because temperatures in excess of 100°C are required the system must be pressurized, both for heating and cooling. Research continues, for example at the U.S. Army Natick Labs; they have built special pressurized microwave equipment to study the processing parameters involved in heating and cooling flexible packs of food (Kenyon *et al.*, 1971; Ayoub *et al.*, 1974).

The examples so far have utilized heating times of the order of a few minutes, which constitutes a considerable shortening over conventional heating methods. But even these microwave heating rates are modest in comparison with those potentially possible in special circumstances. Where we have a foodstuff being pumped through a pipe the microwave zone can be very compact; with high microwave power being absorbed in a small volume the heating time can drop to less than a second.

Some years ago we studied the sterilization of milk using microwaves to achieve extraordinarily short heating times (Unilever, 1970; Assinder, 1974). Ultra high temperature processes employing temperatures of say 140°C for a few seconds yield milk that tastes fresher than the product from lower temperature longer time sterilization. We were investigating the effect of higher temperatures and shorter times on flavour and sterilization. There is no benefit in achieving a very fast heat up and a short hold at high temperature, unless the product is also cooled extremely rapidly, so we had to devise a special form of apparatus.

We had to overcome the additional problem that if very hot milk is in contact with a surface, a deposit gradually builds up. If this is in the microwave zone, this deposit burns. Therefore, the whole process of heating, holding and cooling was carried out with a free falling jet of milk not touching the walls of the equipment, which was pressurized to prevent boiling because the temperature rose to 200°C. The heating time was about 40 msec with a throughput of 25 kg/hr at 5 kW microwave power. Holding at 200°C occurred during the free fall which lasted 130 msec, and virtually instantaneous cooling was achieved by turbulent mixing of the hot milk with jets of cold sterile milk before reaching the base of the container. Thus only cold milk was in contact with solid surfaces. The sterile milk was kept cold by recirculation through a heat exchanger and was taken off at a rate to balance the hot milk input. This extreme high temperature short time process yielded a sterile product virtually indistinguishable from the starting material. Although technically successful, the process was too complex and costly to develop.

Blanching

Blanching of vegetables is an area where considerable work has been done to establish whether microwaves can offer an improved process (Anon, 1970; Dietrich, Huxoll & Guadagni, 1970). A big problem with the conventional methods using water or steam is the loss caused by leaching of solids—nutrients and flavours—during the prolonged contact with water. The claim for microwaves is that reduced heating time and the dry process improves the yield of solids. But without cold water the cooling stage is prolonged and there is some desiccation. Whether there really is any worthwhile improvement of quality is questionable but the reason that blanching of vegetables has not become a factory process is the economic one. Microwave equipment is expensive and should be used throughout the year rather than on seasonal operations like vegetable blanching.

Change of state

Defrosting

A range of important food raw materials are deep frozen in order to preserve their quality during transport and storage. Meat and fish are prime examples, and factories have the problem of thawing or tempering large blocks of the frozen material prior to further processing. Various procedures are used, a common one being to place the blocks in tempering rooms where they may stay for several days while reaching the desired temperature. In order to accelerate the process, warm air or water have been used; unfortunately, although these steps speed up thawing rates, they also tend to degrade the product. As the surface is warm for a long time, drying by air or leaching by water may occur, and there is a bacteriological hazard.

An opportunity exists here for the use of microwaves, which have a considerable penetration depth into frozen organic material. In theory, by overcoming the heat conduction problem, operations taking 24 hr or more could be reduced to a few minutes. A major difficulty prevents the straightforward use of microwaves in this application. The problem is that water absorbs power much more readily than ice, on account of relative dielectric properties. As soon as water is formed in any part of the food, then gross differential heating starts; the water absorbs energy and rapidly heats up, while large parts of the block are still frozen, a phenomenon known as thermal runaway. In general, surface regions will thaw first, absorb an ever increasing proportion of the available power and prevent effective power from reaching central regions.

So any operation involving complete thawing is fraught with problems. On the other hand, microwave tempering is much more attractive, i.e. raising the temperature of meat or fish to about —3°C. By taking care to avoid water formation, the thermal runaway does not occur and successful tempering should be possible. Applications to meat and fish blocks (Meisel, 1972) and to shrimps (Anon, 1973) have been reported. However, difficulties arise from irregularities in the food, e.g. salt pockets and voids in meat, which give rise to uneven heating (Decareau, 1975).

There are several manufacturers of large-scale tempering equipment including ABR,* Raytheon† and L.M.I.‡ The latter have introduced refrigerated air into the microwave tunnel to try to reduce thermal runaway. The equipment can temper in 10–30 min with throughputs from half to several tons per hour. The short thawing times can lead to simpler factory management. It is also claimed that drip loss is reduced with economic benefit, but the gain is only real if the drip is normally lost and not incorporated in the later stages of processing.

Dehydration

There are two distinct transfer phenomena that control drying rates and one or the other normally dominates in a particular drying situation.

One of these limiting mechanisms is the rate at which water vapour can diffuse to the product surface in order to escape. A process whose drying speed is limited by diffusion is mass transfer limited. Any attempt to increase the drying rate by putting in more heat, is accompanied by temperature rise. So if the upper permissible temperature limit for the product is reached, then no further increase in speed can be achieved.

The other limiting mechanism is the rate at which heat can be supplied to the product interior in order to promote evaporation. No matter how porous the material is to water vapour, the drying speed will be limited by heat transfer across the product surface and subsequent conduction, i.e. the process is heat transfer limited. In conventional processing the heat transfer is increased by raising the surface temperature (e.g. using hotter air) but this is limited by the need to avoid heat damage.

Examples of process limited in these ways, might be drying of vegetables (mass transfer limited) and drying of a porous sponge (heat transfer limited). We can at once see which of these two types of process could benefit from microwave heating. In the mass transfer limited process, there will be no benefit from internal microwave heating and the most probably result will be a scorched product; heat transfer limited processes, however, can be expected to benefit from the extra rate at which microwaves can supply heat internally.

Heat transfer imposes a severe limitation to the freeze drying process. At first sight microwave heating would appear to be a natural answer to the problem as microwave

* ARB Food Machinery Co. Ltd, Bletchley, Milton Keynes.

† Raytheon Co., Waltham, Mass., U.S.A.

‡ Les Micro-Ondes Industrielles, Epone, France.

energy passes through a vacuum, and heats the food internally. Although microwave freeze drying has been studied for many years, no commercial process has evolved: this is probably due to the poor economics as well as technical problems such as the tendency to thermal runaway, and corona discharge which can occur in a very low pressure atmosphere (Grimm, 1969; Ma & Peltre, 1975).

Microwave heating is also being applied by LMI to vacuum dehydration, where the pressure is not so low as in freeze drying and the food is not frozen (Huet, 1974). Especially when the food forms a foam in the vacuum, the ability of microwaves to heat such a good thermal insulator is an advantage over the conventional vacuum drier with its heated belt or trays. This should lead to much shorter drying times.

The thermal drying of potato crisps at one time accounted for most of the installed microwave power in the food industry (Anon., 1969; Porter *et al.*, 1973). The problem that needed a solution was the excessive discolouration that occurred during frying when potatoes of high reducing sugar content were used as raw material. The occurrence of such potatoes was both seasonal and variable from year to year, the sugar level depending on weather conditions during growth. A large part of the harvest was often unsuitable for production of crisps and made raw material costs high.

When it was discovered that if the crisps were subjected to finish drying by microwaves after frying to the correct colour acceptable products resulted even if high-sugar potatoes were used, it was believed that any capital cost expended to introduce the microwave systems would be repaid in a very short time in terms of raw material cost savings.

Unfortunately many factors combined to render the process obsolete, and these are discussed as a case history by O'Meara (1973). The main factors were: the difficulty of controlling the final moisture content at a low enough level, with attendant texture problems; the organization of the industry into fewer larger units; and the installation of improved raw potato storage facilities, so that the need to use high sugar potatoes tended to disappear. In fact the microwave process had stimulated the development of improved and new processes based on conventional technology. Since the original problems have disappeared the outcome is that microwave terminal driers have become obsolete and are no longer used for crisp production.

In contrast the drying of pasta is proving successful (Maurer, Trembley & Chadwick, 1971; Anon., 1974). The process uses a combination of microwave heating with hot air for drying. Ordinarily pasta is dried at around 40°C in controlled humidity and it takes about 10 hr. These conditions are ideal for bacterial growth so that bacterial contamination is an ever present problem. The driers have to be very large to cope with the long drying time. Typically the microwave process consists of a first stage air drying to around 25% moisture, followed by drying with microwaves combined with air at about 100°C and ending with cooling in a controlled atmosphere. The overall time is about half an hour. The advantages are: great saving in floor space as the equipment is compact, negligible bacterial problems as high temperatures are used, the product is claimed to have improved rehydratability, and the overall energy consumption is reduced. Several pasta manufacturers in the U.S.A. are using the process with equipment made by Microdry.*

Cooking

There have been many ideas for cooking with microwaves, but for many the high capital cost of microwave equipment rules them out when conventional methods are cheap. Nevertheless, some processes are viable.

The precooking of chicken parts by combined microwave and steam heating had considerable publicity (May, 1969; Smith, 1972). Plants with throughputs of 1·5 tons/hr have been described. The product advantages claimed included reduction in bone darkening and a succulent product. On the economic side, the extra cost of processing was to be more than offset by increased yield and reduced processing time. In at least one operation an important fact was lost sight of: the final breaded chicken pieces were sold on an item basis and not on a weight basis. So the money and effort put into increasing the yield was wasted. This should have been realized without doing any microwave work. However, another manufacturer has used a microwave process for cooking chicken for several years.

A process has been developed in Sweden for cooking meat patties prior to freezing, using a Scanpro† microwave tunnel (Bengtsson & Jakobsson, 1974; Nilsson, 1975). The process has superseded deep fat frying with the following advantages claimed: a shorter processing time and improved economy resulting from higher yields and lower fat usage.

Precooking can also be used to heat set meat to make it suitable for subsequent process operations or handling. An example of this type of operation has been demonstrated by ABR. Comminuted meat is extruded through a plastic tube passing through a microwave applicator, where in a short heating length the meat is heat set in about a second, and emerges as a rod and is cut into lengths. The compactness, high speed, cleanliness and efficiency make this process attractive. It opens up the possibility of producing skinless sausages without the use of temporary casings thus making the process cheaper.

Also in the meat industry microwaves have been used to precook bacon (Lactronica & Ziemba, 1972), and at the Natick Laboratories there is a study using a special oven employing two microwave frequencies, infra-red, and steam to find the optimum combination for roasting (Decareau, 1975).

In the bakery industry there is one of the most successful applications of microwave power in the food industry in U.S.A. (Schiffmann *et al.*, 1971). This is the doughnut proofing system developed by DCA Food Industries.‡ The proofer was developed to

* Microdry Corp., San Ramon, Ca., U.S.A.

† Skandinaviska Processinstrument AB, Bromma, Sweden.

‡ DCA Food Industries Inc., New York, U.S.A.

provide a rapid, compact, hygenic means of proofing yeast-raised dough with little labour. Conventional proofers tend to be large, slow, labour intensive, difficult to clean, and difficult to control. The microwave system reduces the proofing time from 30–40 min to 4 min, and does it with production cost savings. More than twenty units have been installed.

DCA have also developed a microwave doughnut frier. Microwaves are combined with deep fat frying to provide larger doughnuts from a given weight of dough with better quality than from conventional frying. It is the property of microwaves to generate heat internally that is being used here to advantage by the baker.

The use of microwave energy combined with hot air for baking bread has also been studied (Chamberlain, 1973). The process has been shown to be technically feasible and can utilize soft wheat flour. However, the very high air temperature gives rise to the problem of finding a suitable container for the dough that is transparent to microwaves, i.e. non-metallic.

Other applications

There have been numerous other ideas for exploiting microwaves for a wide variety of foods and associated operations. A few examples are listed here, without any attempt at completeness or criticism.

Pasteurization of hams (Bengtsson, Green & Del Valle, 1970)
Dehydration of potatoes and apples (Huxoll & Morgan, 1968b)
Quick cooking rice (Huxoll & Morgan, 1968a)
Cooking meringues (Baldwin, Upchurch & Cotterill, 1968)
Inactivation of alpha-amylase in flour (Aref, Noel & Miller, 1972)
Controlling insects in stored grain (Nelson, 1972)
Heating soya beans to improve the nutritional properties (Wing & Alexander, 1975)
In Japan, preparation of snack products, roasting Laver (a seawood food) and roasting nuts (Suzuki & Oshima, 1973)

Finally, the activity in the field of the use of microwaves for catering should not go without mention. *The Journal of Microwave Power*, for example, carries reviews of this aspect as well as reviews of microwave heating in industrial application (see, for example, Vol. 8, p. 123–78). Bengtsson & Ohlsson (1974) have also reviewed industrial applications.

Economics

The economic aspect must be examined when considering ideas for microwave heating. As a source of heat, microwaves are basically expensive and the capital cost is high. Therefore the maximum utilization of equipment should be aimed for, and ideally the applications should be to processes operating all the year round and operating continuously rather than batchwise. The introduction of microwave heating can have repercussions on other parts of a process and therefore cost comparisons should be done on whole processes from raw material to final product, that is if conventional processes exist. Savings sometimes appear from places that are not obvious, but in doing comparisons, at least the following should be included.

Services (electricity, steam, water, gas)
Capital (depreciation)
Maintenance
Labour (and the degree of skill used)
Cleaning
Space
Yield of product and wastage

Rough costings should be done as soon as they can realistically be done in a project. Some examples have been given where effort was wasted by not stopping uneconomic projects. Where economics are reasonable one can obviously consider proceeding with technical development.

Conclusions

In considering whether to invest capital in microwave heating, a food processor should acquire a sufficient understanding of microwaves, of the advantages and the pitfalls, and benefit by past experience of the projects that have gone wrong (O'Meara, 1973) and those that have succeeded. He should systematically examine both the technical (Bedrosian, 1973; Assinder, 1974) and economic aspects at the appropriate stages of a project.

Microwave heating is so different from conventional heating that its use should be borne in mind when technical problems arise with products and processes. It should also provide new thinking that may sometimes result in improved traditional techniques, but also generate new ideas.

Microwave heating on its own has not led to many viable processes. Rather it is the combination of microwaves with conventional sources of heat that has generated the recent successes like pasta drying and doughnut frying. It is the combination that has been somewhat ignored in research and development. Here probably is the greatest potential.

Appendix

Microwave characteristics

Microwave heating differs radically from conventional heating. It has a number of characteristics that need to be appreciated in the assessment of potential ideas and the development of applications, whether or not it is allied with conventional heating.

(a) Microwaves generate the heat directly within the food. Heat transfer at the surface and heat conduction internally are not involved except as secondary effects that modify the temperature distribution. They show to particular advantage in heating foams, e.g. sponges, which have a structure that makes them naturally good heat insulators, and are most difficult to heat conventionally.

(b) Microwaves can generate rapid temperature rises, very rapid in special cases; but this advantage may sometimes be offset by a limitation that only conventional processes are available for cooling.

(c) Microwaves cannot heat food inside cans or aluminium foil containers because metal acts as a barrier and reflector of microwaves. This property is used in equipment to confine and control microwaves to heat in specific ways.

(d) Microwaves readily pass through many materials which can be used to contain food, e.g. polythene, polypropylene, paper, glass.

(e) When a food is being heated by microwaves the generation of heat is continuous and so there is a continuous rise of temperature. The longer the microwaves are applied the higher the temperature and there is no automatic limit to the temperature reached, in contrast to conventional heating in which the food does not rise above the temperature of the heat transfer medium. If the food is wet, microwaves raise the temperature to 100°C when the continued generation of heat boils off free water. When the free water is gone there is nothing to hold the temperature at 100°C any more and the temperature of the nearly dry food can rise rapidly with the risk of burning.

(f) Both wet and dry food can be heated by microwaves, but wetter food is heated more strongly than drier food. This effect is more marked when wet and dry food are present together. Other differences in composition (e.g. lean, fat, salt content) can also cause differential heating.

(g) Uneven heating also happens as a result of the geometry of the food. In an ordinary microwave oven a frequent phenomenon is edge overheating (e.g. a disc of meat). A flat rectangular slice may have not only exhibit edge overheating but corners heating even more so. Thin sections may heat more than thick ones. Not only shape but also size is important. For example, if an apple is heated by microwaves the core boils before the skin gets hot, but when the sphere is large enough the surface heats more than the centre. Nevertheless, a great deal can be achieved by specially shaping the microwave applicator and also the food to get reasonably even heating. When uniform rise of temperature is achieved, reproducible final temperature requires reproducible starting temperature, or automatic control to allow for varying input.

(h) One of the most difficult situations is thawing when thermal runaway may easily happen. This is due to the fact that water absorbs microwaves more strongly than ice. So the first region to thaw tends to preferentially absorb the microwave power and runaway in temperature, and boiling may occur close to a still frozen region.

References

AREF, M.M., NOEL, J.G. & MILLER, J. (1972) *J. Microwave Power*, **7**, (3), 215.

ANON. (1969) *Microwave Energy Applications Newsletter*, **2**, (6), 12.

ANON. (1970) *Microwave Energy Applications Newsletter*, **3**, (1), 6.

ANON. (1973) *Microwave Energy Applications Newsletter*, **6**, (4), 3.
ANON. (1974) *Fd Proc. U.S.* **35** (9), 25.
ASSINDER, I. (1974) *Trans. IMPI*, **2**, 92.
AYOUB, J.A., BERKOWITZ, D., KENYON, E.M. & WADSWORTH, C.K. (1974) *J. Fd Sci.* **39**, 309.
BALDWIN, R.E., UPCHURCH, R. & COTTERILL, O.J. (1968) *Fd Technol., Champaign*, **22**, 1573.
BEDROSIAN, K. (1973) *J. Microwave Power*, **8**, 173.
BENGTSSON, N.E., GREEN, W. & DEL VALLE, F.R. (1970) *J. Fd Sci.* **35**, 681.
BENGTSSON, N.W. & JAKOBSSON, B. (1974) *Microwave Energy Applications Newsletter*, **7** (6), 3.
BENGTSSON, N.E. & OHLSSON, T. (1974) *Proc. IEEE*, **62**, 44.
CHAMBERLAIN, N. (1973) *Fd Trade Rev.* **43** (9), 8.
DECAREAU, R.V. (1975) *Microwave Energy Applications Newsletter*, **8** (2), 3.
DIETRICH, W.C., HUXOLL, C.C. & GUADAGNI, D.G. (1970) *Fd Technol., Champaign*, **24**, 293, 613.
EVANS, K.A. & TAYLOR, H.B. (1967) *Fd Mf.* **42** (10), 50.
GRIMM, A.C. (1969) *RCA Rev.* **30**, 593.
HUET, R. (1974) *Fruits*, **29**, 399.
HUXOLL, C.C. & MORGAN, A.I. (1968a) *Cereal Science Today*, **13** (5), 203.
HUXOLL, C.C. & MORGAN, A.I. (1968b) *Fd Technol., Champaign*, **22**, 705.
KENYON, E.M., WESTCOTT, D.E., LA CASSE, P. & GOULD, J.W. (1971) *J. Fd Sci.* **36**, 289.
LATRONICA, A.J. & ZIEMBA, J.V. (1972) *Fd Engng*, **44** (4), 62.
MAURER, R.L., TREMBLAY, M.R. & CHADWICK, E.A. (1971) *Fd Technol., Champaign*, **25**, 1244.
MA, Y.H. & PELTRE, P.R. (1975) *A. I. Ch. E. J.* **21**, 335, 344.
MAY, K.N. (1969) *J. Microwave Power*, **4**, 54.
MEISEL, N. (1972) *Microwave Energy Applications Newsletter*, **5** (3), 3.
NELSON, S.O. (1972) *J. Microwave Power*, **7**, 231.
NILSSON, K. (1975) *Quick Frozen Food Int.* **16** (4), 62.
OLSEN, C.M. (1965) *Fd Engng*, **37** (7), 51.
O'MEARA, J. (1973) *J. Microwave Power*, **8**, 167.
PORTER, V.L., NELSON, A.I., STEINBERG, M.P. & WEI, L.S. (1973) *J. Fd Sci.* **38**, 583.
SCHIFFMANN, R.F., ROTH, H., STEIN, E.W., KAUFMAN, H.B., JR, HOCHHAUSER, A. & CLARK, F. (1971) *Fd Technol., Champaign*, **25**, 718.
SMITH, D.P. (1972) *Microwave Energv Applications Newsletter*, **5** (4), 3.
SUZUKI, T. & OSHIMA, K. (1973) *J. Microwave Power*, **8**, 149.
UNILEVER (1970) G.B. Patent 1187766.
WING, R.W. & ALEXANDER, J.C. (1975) *Can. Inst. Fd Sci. Tech. J.* **8**, 16.

(*Received* 5 *February* 1976)