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Microwave ovens and some industrial food applications in Northern Europe

Historical perspectives come with one's own age, and with the maturity of the discipline of concern. But do recollections and descriptions of what has happened tell anything about the future? Is there a continuous and concerted path of progress, or have there been some dead ends and quantum leaps?

Even if the history of microwave heating began already in the 1930's, coherent developments of technology and applications did not occur until after WW2 – 60 years ago. But there have always been technology differences between in particular Europe and the US. This rhapsodic article is limited to mainly microwave oven technology, the edge overheating effect, and some related aspects of the developments of microwave processing of ready meals.

The general development of the microwave power industry.

There are many good publications dealing with the historical developments, but there is often a focus on udescriptions on who did what and when, rather than applying a wider perspective. The following choices give quite good overviews at different times:

H. Püschner, *Microwave Heating technique in Europe*, presentation at the 2nd IMPI symposium, 1967.

N. Meisel, *Microwave applications to Food Processing and Food Systems in Europe*, JMP 8 (2), 1973

J. Thuery, *Microwaves: Industrial, Scientific, and Medical Applications*, Artech House, 1992

N. Bengtsson, *Development of industrial microwave heating of foods in Europe over the past 30 years*, JMPEE (36, No 4, 2001)

There was a general optimism in industry, beginning in the early 1950's and lasting until about 1965. Rapid technical improvements of key components such as the magnetron and rectifiers opened up new "dimensions of equipment and processing". Many large companies invested in the technology, and they all understood that this was not an investment toward improved quarterly profits within a year. For the same reason, and for minimising financial risks, they also understood that a rather open exchange of knowledge may be more beneficial than harmful – components were still expensive and vulnerable, and there was a general need for *microwave physics* knowledge. So most of the individuals doing the R&D had higher engineering or scientific educations and were inclined to meet and publish.

In the last years of the 1960's, two major books were written (in Europe by Püschner and in N America by Okress (ed), and IMPI was founded. At that time, reports of technical failures and unexpectedly few successes surfaced. There was also a world-wide recession, so a drastic slowdown occurred. The optimistic exploratory phase ended. Many large European companies gave up, handing over the baton to a number of smaller companies, in UK, France, Germany and Sweden.

Beginning in 1968, Nils Bengtsson and Thomas Ohlsson at SIK in Sweden, in co-operation with the Swedish microwave oven industry and Alfastar (see below), started long-range microwave physics research projects, as did MIT in the US (Bob Decareau). So it may be suitable to now address the European microwave oven industry.

50 years of European microwave oven industry

Just after WW2, 2450 MHz diathermy magnetrons began to be produced by Philips in Hamburg and Deutsche Mikrowellen in Freiburg. Krupp was involved also. Sufficiently stable and cost-effective German magnetrons with 1300 to 1600 W output power became available about 1955. Deutsche Mikrowellen was bought by Husqvarna of Sweden in 1956; the magnetron production remained in Freiburg and microwave oven production began in Sweden the following year. Drawings of several German oven designs (not just being floor models with very large cavities) were used by Husqvarna, and the first such oven was produced in Sweden 1957 (Fig.1, next page). By 1960, Husqvarna produced several hundred tabletop commercial microwave ovens annually.

The Philips company had a very successful military microwave R&D and production business in Sweden in the 1950's, and in 1962, its microwave oven R&D activity was moved to Sweden. As a result, and due to problems in other European microwave oven companies, Europe's two largest oven manufacturers were now both in Sweden, and only 150 km apart. Each produced at least 2000–4000 commercial microwave ovens per year from about 1964. Even if more than 80 % were exported, virtually all restaurants, bars and similar in Scandinavia (except Norway) had a microwave oven in 1972. Both also successfully exported ovens to the US.

Oven R&D was strong in both companies, with resonant stirrers and elaborate bottom feeds. Particular

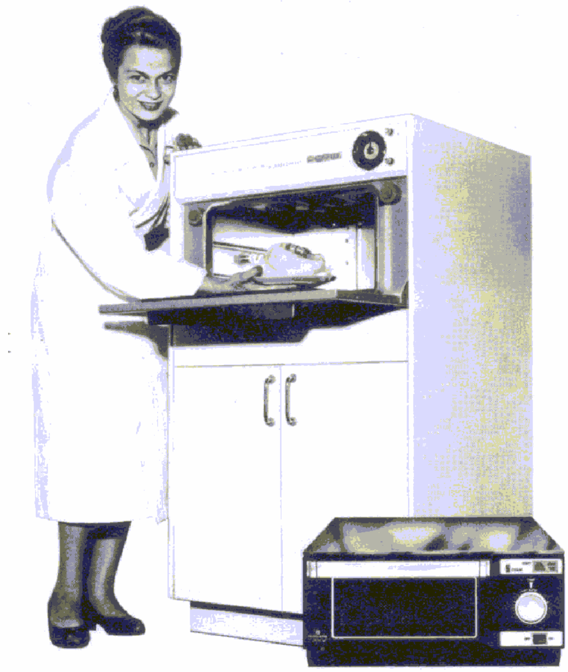

Fig.1. Two Husqvarna ovens: a 1957 floor-standing unit, and a 1972 commercial 1200 W oven with near-field cavity and the world's first automatic humidity sensing control. Note the choke seal in the old oven (the Schmidt patent).

safety standards for microwave ovens had become law in Sweden already in 1964, and when the US authorities (then Bureau of Radiological Health) made a field survey of microwave oven leakage in 1970, the Husqvarna ovens came out as clearly the best, the Philips ovens were also good, but many US-produced models leaked excessively.

But changes were to come. Already about 1968, some Japanese companies had succeeded in drastic cost reductions in 750 W magnetron production, maintaining the quality. Some key Raytheon and Litton patents were to lapse some few years later, but had not disturbed Husqvarna and Philips. After having built up a strong home market, the Japanese manufacturers began what would at the end of the 1970's give them world leadership in oven production. But oven performance was not much improved, as evidenced by the increasing publicity in Europe of the results obtained by test methods developed by the International Electrotechnical Commission (IEC) from 1975 and onwards. So from this time, ovens were characterised by diversified oven performance and price reductions. Husqvarna ceased their oven production in 1977, when the company was bought by Electrolux, which then bought Tappan in the US. The Philips activity continues to-day, but was bought by Whirlpool in the US in the mid 1990's.

The "pendulum of industrial activity" clearly began to swing back towards product development about 1988. But the question was now: what performance factors could be improved so that customers would prefer such ovens at a slightly higher price? Was it at all possible that such features would provide at least a delay of the take-over of microwave oven manufacturing by inexpensive labour in the far east?

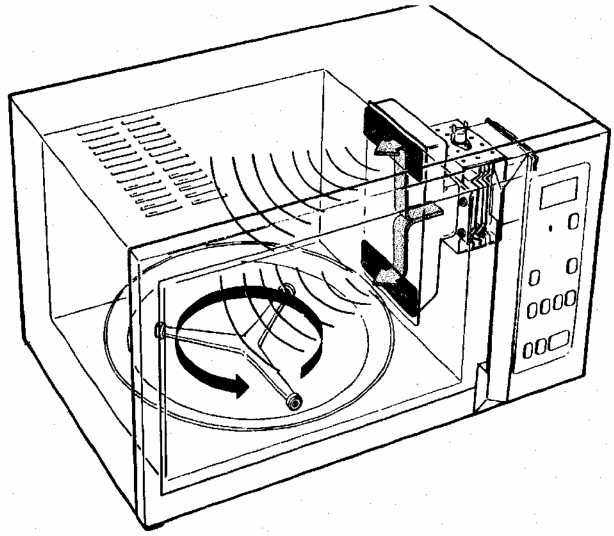

Fig.2 Illustration of the Whirlpool *DES* system.

The figure cannot possibly show the complexities of an inherently resonant waveguide and enforced low impedance hybrid modes and trapped surface waves in the cavity. But does the average reader really want to know all this?

A part of the answer was improvements in added browning element functions and full combination microwave oven designs (grill elements and forced air). Such ovens had for many years been sold in Europe and now grew to represent almost half of the total sales value of ovens produced in Europe. But it turned out that these added features were quite easily introduced by SE Asian manufacturers as well.

In my view, one of the most successful features was a Whirlpool technology (dubbed DES, double emission system, see Fig.2). It brought a combination of improved performance (less edge overheating, possibility of full power defrosting) with a useful and efficient accessory (metal pans with microwave-absorbing ferrite cladding on the underside). Ratings by consumer institutes (both government-sponsored as in Scandinavia and some other countries, and independent such as in Germany and France) hit new records for the first such Whirlpool oven in 1992. Efforts by several large manufacturers to circumvent or attack the patent failed. In 1998, Whirlpool was #1 in European microwave ovens sales, and #3 globally. Another result of the performance race was some other manufacturer's ovens, such as by Matsushita/ Panasonic in Japan and De'Longhi in Italy, were improved during the 1990's.

With the DES system as reference, further essential performance improvements of the very general function of the household microwave came to an apparent stop. The reason is that the food load itself (geometry, packaging, accessories) must always have an influence on the heating distribution, and the microwaves emanating some distance away from the load are not possible to manipulate strongly enough for avoiding this inherent load effect.

As evidenced by the now dominating Chinese manufacturing of microwave ovens, perhaps only a single-digit percentage of the market remains for more advanced or designer microwave ovens. And ovens with a good performance may be no more expensive to mass-produce than poorly performing ovens.

Overcoming the edge overheating effect

One of the most difficult and also interesting problems is the microwave overheating of edge regions of in particular compact food items. As just mentioned, the DES system in microwave ovens provides a solution, but it does not serve well in industrial tunnel ovens where there is a large multifed cavity or multiple open-ended applicators.

The problem of microwave overheating of edges of in particular food items with high water content effect has been known for over 30 years. In some literature from even the 1990's, a simple optical analogy is used to explain the phenomenon: "the field impinges from two directions at the edge, so this gets twice as much power". However, the effect is a non-resonant diffraction phenomenon caused by the electric field component parallel to the edge, and may be six to ten times stronger than the heating of parts away from the edge.

The edge overheating effect is of interest also because it is a problem which equipment engineers have – directly or indirectly – hoped that academia would analyse qualitatively and provide ways to control. But that has not occurred. And the food processing microwave equipment industry began struggling with it more than 30 years ago.

During the 1970's, the first comprehensive attempt to reduce the effect in ready meal processing was by the very large Swedish Alfastar/Multitherm project. The

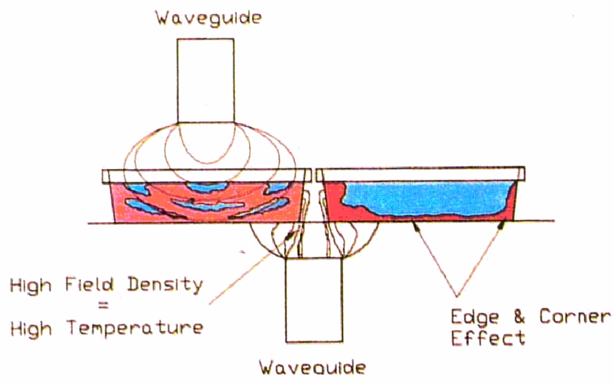

Fig.3 Illustration of simple waveguide applicators for food pack pasteurisation (from Berstorff, 1992). In order to overcome the problems with edge overheating (and also surface waves, as seen in the illustration), applicators were energised only for short intervals when at pack centres.

sealed food packs were processed in a pressurised water-filled microwave tunnel, at more than 100 °C. Since such hot pure water has a much lower microwave absorption than the food (due to the ionic content in foods), but about the same dielectric constant as the food items, the "focusing" should disappear and a reasonably high efficiency also be expected. However, the project died after several years, for reasons of continuing packaging integrity problems and finally a particular microwave-induced so-called microwave corrosion effect in the applicators (the effect and its causes are known and have been dealt with in the IEC microwave oven safety committee).

During the 1980's, a second comprehensive attempt to reduce the edge overheating was by the Berstorff company in Germany. Still, there was no consideration of field polarisation and impedance, so simple TE10 waveguides above and below the load items were used to "irradiate" them. The edge overheating effect, as well as surface waves bound to the load caused problems (see Fig. 3). There was an improved heating evenness when loads were "irradiated" only when straight below/above the waveguide openings. But installations became more expensive due to the need for higher power during shorter times, and a need for careful adjustment of timing and exact load placement. Some installations were sold, but Berstorff later stopped their food adventure and returned to their successful microwave vulcanisation installations – where there is much less edge overheating due to the low permittivity of rubber.

The third comprehensive attempt is related to basic considerations behind the DES invention mentioned earlier. After that, beginning in the 1990's, proper conditions for some related mode types in open-ended applicators were further developed. Such systems are now used in tunnel ovens in Scandinavia, for ready meals and other applications. The new technology ("HERA", hybrid evanescent resonant applicators) was described at the latest AMPERE conference. The applicators are essentially single mode, and the mode is characterised by a very low vertically directed impedance which results in a very low horizontal electric field and only in one horizontal direction. The necessary balance between electric and magnetic field energies is by a strong vertical electric field which is thus not parallel to the load edges. However, it is still to early to tell whether this new industrial microwave technology will become commercially successful.

'Scientific efforts vs industry developments

Similar research problems to those related to the edge overheating effect also apply to multimode systems. In spite of the perceived engineering simplicity, multimode cavity theory can be characterised as follows:

- Complex theory – not good for planned academic research.
- Theory for empty or very simply loaded cavities dominates in the literature – but many important phenomena occur only in realistically loaded cavities.
- The stirrer compensates the cavity sensitivity – but only statistically and the resulting behaviour becomes difficult to qualitatively analyse. The importance of studies of the behaviour of particular cavity modes diminishes.
- The heating result is also quite influenced by the load itself – theoretical complications lead to engineering designs mainly by experiment.

So how is the microwave equipment industry in general reacting?

Specialisation to a limited number of proven system designs and applications has been the way towards operational stability among the serious manufacturers, for many years. But that also means that they have only a small need for new inputs provided by academia.

Inexpensive household microwave ovens can be used for process testing, and parts from disassembled such ovens then for building equipment for further testing. It is a fact that such quite simplistic and purely experimental approaches are increasing everywhere. There is an expanding category of producers of microwave installations, with the majority of such companies being small, relatively local, having limited expertise and an opportunistic sales approach. I estimate that about or more than 50 % of the present installation rate in kW/year in Scandinavia and Germany comes from such companies. A vast majority of these companies seem to have no interest in or even knowledge about the AMPERE activities.

And the future?

The present situation is thus quite mixed. The times when big companies invested in new technologies is over – the unhealthy stress on quarterly profits has probably forever changed the way, where and which new technologies and applications emerge and are financially supported. One of the consequences is today's tendency with start-up companies backed by investors having a focus on a profitable exit in some few years rather than building a stable new industry or application area. Quite often, the lack of comprehensive experience creates a condition for a low success rate. Another unfortunate effect is that industry is increasingly protecting its interests by patent applications and secrecy constraints.

Another kind of activity is research projects co-funded centrally by EU, with technology transfer within academia and to industry as a goal. Earlier on, there were similar national projects in some European countries. The complexity of these issues is beyond the scope of this article.

As communication and information over the Internet is expanding, also a number of rather small, serious and stable European companies providing new or tailored solutions to experienced and knowledgeable customers are finding a market. And the Internet also provides possibilities for special interest groups to be formed – with members from both academia and industry – and with an openness that gives opportunities for a quicker general development of particular technologies and applications.

The correlation between areas of academic research and what goes on in industry was quite high up to the end of the 1980's but has since then gone down. Additional explanations for this are application maturity, and the "publish-or-perish" and "we-too" syndromes in academia (too much of uninteresting or repeat research in areas where valid results have been published earlier). And finally, the availability of very good microwave modelling software and inexpensive computers are now making it increasingly possible for industry – itself or through consultants – to make progress in understanding and design.

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