DESPITE THE CREDIT CRUNCH MICROWAVE AND RF USE IN INDUSTRY MARCHES ON

Although the penetration of microwaves and RF into industry is not immuned to fluctuations in energy costs, compounded of course by the ongoing credit crunch, the impact in this sector is not as severe as one might expect because of the niche aspect of this form of energy use. Sure enough manufacturers of microwave and RF equipment are forced to lay off workers and scale down their operations but they are still able to offer users equipment with specific advantages over conventional equipment fuelled by gas or oil. These include volumetric and selective heating, compact equipment, ability to level the moisture across broadloom paper and reduced harmful emissions. It would be preferable also for the electricity to be produced by renewable energy which will reduce the impact on harmful emissions even further.

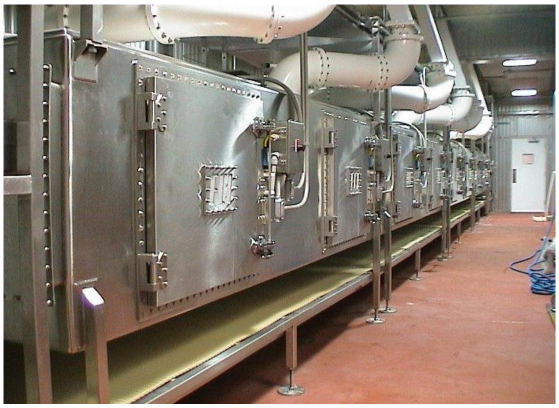
Although in principle microwaves and radio frequencies (RF) can be used to process most dielectric materials in industry, a distinct division of areas have been established over a number of years [Metaxas, 1996]. Microwaves at 2450 and 900 MHz are well established in tempering, rubber vulcanisation and drying under vacuum while RF at 13.56 and 27.12 MHz found repeat applications in large scale drying such as in textiles, adhesives and in the processing of foodstuffs. Plastic welding also represents some half of the total load for RF.

Processing with microwaves

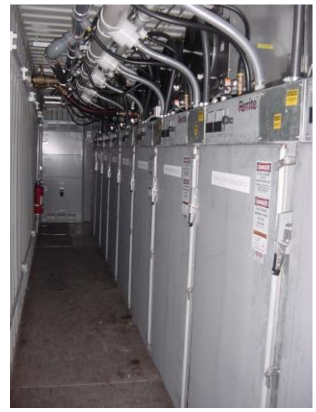
Conventional tempering takes place in large storage rooms and may take between one to four days to complete. During this time drip loss is experienced, which results in lower yields and there is also concern over microbiological control. Meat, fish, fruit, butter and other foodstuffs can, however, be tempered using microwave energy from cold store temperature (around -20ºC) to near -2ºC for ease of further processing such as grinding of the meat in the production of burgers or blending and portioning butter packs. There is great danger of thermal runaway if the foodstuffs are allowed to cross the freezing point and start to defrost. Tempering, therefore, is a much more controlled and safe process of raising the temperature beyond the cold store to a suitable working temperature just below the freezing point of water. The industrial customer can now eradicate loss from errors in long term forecasting demand where, for example, too much or too little meat tempered has been known to result in either wasted meat or lost custom. With multiple generators feeding each processing unit, the opportunity exists to distribute the power so as to give a better excitation of the modes and better uniformity of heating than can be achieved with a single feed, by distributing the feed points around the walls of the oven and by feeding at different polarizations.

Typical continuous systems for tempering frozen blocks of beef, poultry or pork have a power capability of 60 kW allowing the blocks to increase their temperature from

–20^{o}C to between –4^{o}C or –2^{o}C and with a throughput of around 1400-2000 kg/hr. Modular systems comprising of identical units, as shown in Figure 1(a), allow greater throughput. A more recent innovation entails the design of a power source, the GETMAX, capable of delivering up to 1 MW of microwave power in a compact system comprising ten 100 kW magnetron sources.



(a)



(b)

(a) A continuous system for microwave tempering of foodstuffs and (b) the GETMAX system for 1 MW of power (Courtesy of Ferrite Inc USA)

Although as we shall describe below drying with radio frequencies is more established in a variety of foodstuffs, microwaves have also made inroads into this sector. The most established one is the drying of pasta, however, recently microwaves in combination with hot air has been used for drying of sludges. Figure 2 shows a 675 kW microwave sludge dryer operating at 915 MHz.. The combination system also uses hot air from gas burners. The speed depends on initial and final moisture content and bulk density.

Figure 2 Microwave and hot air combination dryer for sludges
(Courtesy of Nemeth-Group Inc USA).

Speciality ceramics can also be dried using microwaves and hot air. The equipment, recently installed in Europe, is shown in Figure 3, is nearly 20 m long, has a microwave power capacity of 60kW and runs at a frequency of 2450 MHz. Careful attention had to be given to the design of the system because of the 2 m wide conveyor and the necessary residence time to get uniform and reliable drying of wide products which are more than 7 cm thick. Sensors and advanced electronic controls assure the reliable high quality repeatability.

Figure 3 Microwave and hot air dryer for speciality chemicals
(With kind permission of Cober Electronics Inc., USA)

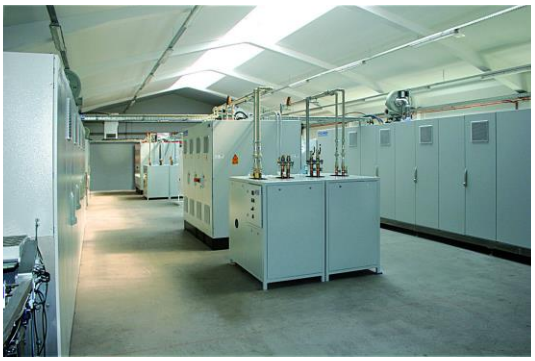


Figure 4 Drying of honeycomb structures for the car industry
(Courtesy of Püschner gmbh, Germany)

Figure 4 shows 4x 60 kW driers operating at 2450 MHz. These are10m long each and are used for drying of honeycomb PDFs for the car industry. The throughput rate is 350 kg/h each drying from an initial moisture content of 30% down to about 15%.

The above examples show the potential of microwave energy in applications where there are clear benefits. Care must be exercised in situations where the product to be dried is seasonal (onions) and large capital investment may remain idle for a large proportion of the year. Some materials are heat sensitive and cannot be dried at atmospheric pressure. It is necessary to reduce the pressure in order to reduce the boiling point and effect drying at a reduced temperature. A modest vacuum around a third of an atmosphere (about 250 torr) is necessary for drying heat sensitive materials with microwaves where the formation of a microwave plasma or arc can be effectively be avoided. Notable examples are the drying of fruit juices, beverages, pharmaceutical powders and various foodstuffs. Integrated processors for mixing, granulating and drying under vacuum using a multi-magnetron 27 kW, 2450 MHz microwave unit has been installed in industry for drugs and other pharmaceutical pellets.

Food products, such as pasta, bread, pre-cooked foods, fruit mixtures and animal feedstuffs have been processed using microwaves for pasteurisation or simply to improve their digestibility. Pasteurisation requires more modest temperatures than sterilisation, that is temperatures of the order of 80ºC, to deactivate vegetative microbes in order to prolong storage time. The process entails three stages where microwaves are used to elevate the product to the required temperature, where it is held for a specific time using conventional energy. Most pasteurisation processes require that the product be rapidly cooled to avoid bacterial infestation and to preserve the quality.

Specific examples include the pasteurisation of bread, fruit and sugar mixtures, prepared meals and pasta products. Also barley has been processed to achieve starch to gelatine conversion. In some products such as bread the use of microwaves can reduce or eliminate the use of additives, such as mould inhibitors, which may have unpleasant organoleptic properties or indeed be prohibited by law. Food pasteurisation of sealed pâté packs under pressure has been effected by a dual mode microwave energy system operating at 2450 and 915 MHz.

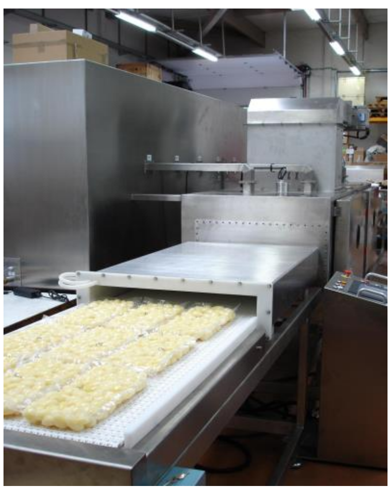


Figure 5 Typical 2.45 GHz pasteurization tunnel (24 or 48 or 76 kW) for fruits, vegetables and ready made meals (Courtesy of Sairem, France)

In microwave pasteurization of ready meals the product have a total life of about six weeks, three weeks in the factory at 1ºC and the remainder on the shelf in a cooler at 4ºC without having to store the food in a freezer and without the use of preservatives. This is accomplished by treating the foodstuffs in the package in a high temperature short time, microwave processor. A 120 kW, 2450 MHz system employing 96 magnetrons processing 1000 kg/h for pasteurizing packages for the consumer market has been in operation for several years. A more recent installation is shown in Figure 5 employing a continuous tunnel suitably choked to reduce the leakage to acceptable levels.

A recent addition from Petrie Technologies to their range of equipment uses a medium sized microwave oven operating at 915 MHz for the baking industry. This unit, the BAMSWA, is intended to bridge the gap between small experimental systems and large bespoke industrial systems in this sector. An example of this batch combination microwave system capable of baking bread, with or without crust, is shown in figure 6.

Figure 6 The BAMSWA oven for the baking industry
(Courtesy of Petrie Technologies, UK).

Drying sensitive granules with conventional energy at atmospheric pressure can be very detrimental. To reduce the temperature, to say 50oC or below a vacuum has to be introduced. A new generation of such system which incorporate many modes of drying is termed single pot processing where mixing, granulation and drying is performed in one machine. Moreover the system provides also for various forms of drying modes, such as gas assisted vacuum, microwaves and swinging bowl. Such a typical system is shown in Figure 7 for processing many pharmaceutical powders such as drugs or tablets.

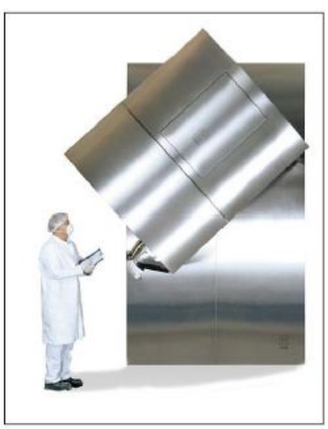


Figure 7 Single pot processing for pharmaceutical granules
(Coutersy of GEA Pharma Systems, Belgium)

Processing with RF

Drying with RF is well established in the textile industry where to date there are over a thousand installations word-wide. This is simply because hot air becomes very

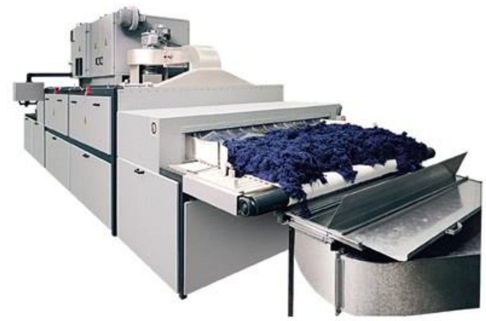


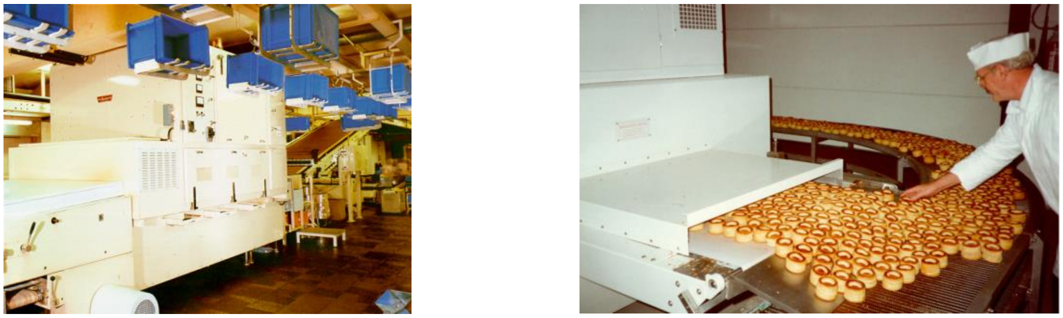
Figure 8 Textile package drying with RF (Courtesy of Strayfield International, UK)

Figure 9 Loose wool drying with RF (Courtesy of Stalam, s.r.l., Italy)

inneffective as moisture contents reduce below a critical point at which point the capillaries get broken and it is more difficult to get the moisture out by heat transfer trough conduction. At this stage RF is able to penetrate the outer parts of the dry material very effectively and remove the moisture trapped in the inner layers (Metaxas, 1996). Suffice to say that it is prudent to remove as much moisture as possible with mechanical means, such as centrifuge or mangling, followed by conventional energy and finishing off with RF. In a typical textile package case, conventional drying using hot air ovens occupies the bulk of processing time, say up to 28 minutes, followed by radio frequency drying for about 5 minutes in a continuous system employing some 75 kW of power and travelling at about 2 m/min. Other examples include drying of woolen loose stock, woolen skins after dyeing, polyester glued yarns, tights (after dyeing at a rate of 1500 dozen pairs per hour) and stockings.

Figure 8 shows three out of twenty six dryers in an installation jn China drying various textile packages with RF while Figure 9 shows a typical continuous dryer drying loose stock at 27.12 MHz. It must be stressed that although drying is the main objective of these installations, the other major advantage over conventional energy is the ability of RF, more so than microwaves, to level the moisture in the package or sheet textile because of the way in which the effective loss factor changes with moisture content.. The required final moisture is generally the natural regain moisture of the fibres, typically, 15-17% for wool, 7-8%, for cotton and 2-3% synthetics.

Post-baking with RF is a long-standing application where energy is used for "drying" of biscuits, crackers and for other cereal and sugar based items. RF effectively removes the thin layer of moisture at the centre of the biscuit created by initially removing the bulk of the moisture with hot air. This is an application akin to drying but the prime consideration here is to level the moisture in the products so that finally they reach the prescribed moisture levels to ensure extended shelf life and optimum condition for packaging. Figure 10 shows (a) a 50 kW RF post baking machine and (b) with final inspection of the "vol-au-vent" product as they emerge from the drying unit. It is fair to note that microwave systems are also used in post baking of biscuits and cerial products but its penetration is far smaller than their RF counterparts.



(a) (b)

Figure 10 Post baking of vol-au-vent type of product using RF
(Courtesy of Strayfield International, UK)

Paper converting takes the form of business forms, direct mail line, envelope making, book binding and a range of varnishes for record covers or publicity brochures mainly of water based adhesives. High speed drying lines have been developed for the more sophisticated single and double-sided adhesive coating applications. A typical 25 kW double-sided installation is shown in Figure 11.

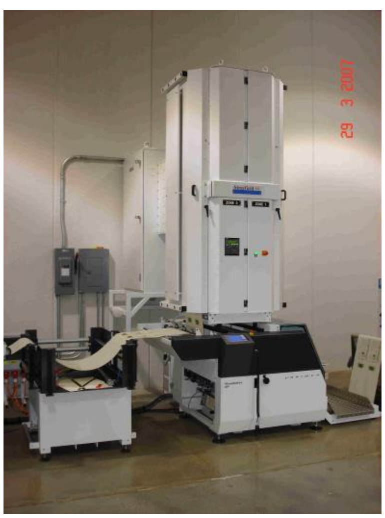


Figure 11 Paper converting with RF
(Courtesy of Strayfield International)

Plastics welding is an established application with thousands of small welders installed in small industrial firms and with power capacity between 1-6 kW. However, a more sophisticated system, the Traveling Welder, shown in Figure 12 was custom designed and built for a reinforced industrial fabric, requiring automated control of very tight seam specifications. The table has a forty-foot working surface and produces a forty-foot seam weld in step-repeat fashion. The system is equipped with a rotary knife, automatic tape feed payout and seam positioning system, articulating parallel vacuum manifolds for containment of both material halves, finished material surface-winder, pneumatically powered roll ejection, and thermally treated bar with both heating and cooling capability.

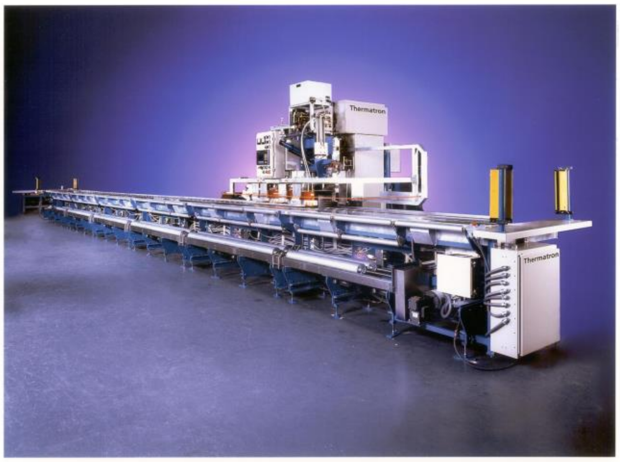


Figure 12 The Travelling Welder for a reinforced industrial fabric (Courtesy of Thermex-Thermatron Inc USA)

Food processing with RF continues to be a major contributor to this technology. However, instead of using the classic design of an aperiodic power oscillator operating under Class C conditions a newer more versatile system is that of the 50 Ohm technology. In such a system a crystal is used to provide low power at a fixed frequency and amplified to give the required power. The output comes out of cable at 50 Ohm

(a) (b)

Figure 13 (a) Continuous online RF, 50 Ohm type meat cooking facility for processing a variety of food products as shown in (b). (Courtesy of Sairem France)

requiring a sophisticated automatic matching and tuning system to couple the energy efficiently to the applicator housing the processed material. A recent example of such a continuous online system installed at Sonder Foods in France is shown in Figure 13 for cooking a variety of cylindrical meat sausages of 60-110 mm in diameter. The total power is 180 kW giving a throughput of 1500 kg/hr.

Overview

Having discussed a number of long standing and more recent installations of microwave and RF energy use in industry it finally remains to put all this into proper context. The first point to emphasize is that, excluding the domestic microwave oven which represents a huge electrical load worldwide, both sectors are small in energy usage compared to other industrial sectors on whatever yardstick one chooses for comparisons. The scarcity of fossil fuel is bound to promote the use of such applications, however, I am reminded in the introduction of one of my earlier publications on this theme following the well documented energy crisis of the early seventies, I quote, “It is well accepted by now that the seventies has been the decade which highlighted the problems associated with diminishing fossil fuels….”. Here we are nearly thirty years hence discussing once again the diminishing fossil fuel reserves which points to substituting inefficient processes using gas and oil with more efficient electrical processes. This in turn requires a major effort in technology transfer again the topic of many AMPERE European conferences in the interim period, the next one being held in Toulouse, France next September. Alas, the last fifteen year have witness the decrease of centres carrying out such a technology transfer, particularly in the UK, fuelled by the privatisation of the electricity supply industry and the consequent demise of the regional utilities through mergers and aquisitions. Despite all this the penetration of such forms of energy continues in key areas within manufacturing industry throughout the world.

Metaxas, A.C., ***Foundations of Electroheat: A Unified Approach***, John Wiley and Sons, ISBN 0 471 95644 9, 1996

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