R.F. Applications In Bakeries

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ABSTRACT
Radio Frequency Heating and Drying has been utilized in the Food Industry since the early 1960’s.

Until recently, with the exception of a number of a few large companies who were quick to recognize and exploit the benefits to their production quality and costs, the value of this technology has been largely overlooked by most food processing companies and is largely unknown amongst younger food technologists.

The technology of RF drying has not been able to find its strength with the food industry at large as the initial visual impact of the capital cost seems large, ignoring the real benefits in quality and consistency of product it produces, in addition to the reduction in production costs achieved, if the same quality of product were to be produced by the other conventional methods.

The paper aims to throw some light on the reasons for the previous lack of enthusiasm for RF heating and drying, and to demonstrate some of the applications and benefits which are now being obtained.

1. A BRIEF HISTORY
Probably well over a million Industrial RF heating installations for various applications have been sold worldwide in the last sixty years.

Radio Frequency Dielectric Heating was originally introduced into the Food Industry in the UK around the beginning of the 1960’s. Early machines were relatively small, air cooled and had simple electrode applicators. They generally suffered from fairly poor reliability, and poor performance.

Strayfield Limited was founded by John Holland in 1969 to supply equipment for Post Baking of Biscuits and has been the market leader in RF dryers in the food industry for many years now, having hundreds of dryers installed in this industry alone and several thousand other RF machines in the Textile, Fiberglass, Paper Converting, Plastic Welding, Pre-heating and Woodworking markets.

Over the years, several other companies have attempted to enter the RF food processing market. Virtually all of these have disappeared after a relatively short time.

Industrial RF heating at high power is a very specialized field and relies to a large extent on knowledge gained through field experience.

Very little, really useful information on this application has been published, apart from the most basic theory. Often, much of the information available, including that contained in patents has been found to be very simplistic. In many cases, it does not work in practice or is just plain wrong.
2. HOW RF WORKS

Basic Theory

RF heaters and microwave ovens offer direct or volumetric heating. The simplest form of RF applicator consists of two metal plates which form an electrical capacitor (see Fig. 1 below).

The product becomes a ‘lossy’ dielectric (hence the alternative name of ‘Dielectric Heating’) and absorbs energy from the RF Generator, which is connected across the two metal plates (generally referred to as electrodes’).

For most products, we are dealing with water molecules, which are ionic in nature, although the technique applies to other ionic substances too. The RF heating process depends upon the ionic conductivity of the material being heated. The effect is analogous to that of two bar magnets. If two like poles are placed together, they repel each other. If two unlike poles are placed together they attract. Similarly, polar molecules have positively and negatively charged ions. If the two electrode plates, between which the material is placed, are charged positive and negative respectively, the molecules will tend to line up all in one direction. If the charge on the plates is then reversed, they will tend to flip around and line up in the opposite direction. Fig. 2 shows the way in which this happens.
Reversing the charge causes the molecules to rub against one another. This causes ‘frictional’ heating. The heating rate will increase as the frequency of reversal of the charge on the plates is increased. Typically this is caused to occur at high frequencies in the Megahertz range. The RF frequency bands used in dielectric heating are centered on 13.56MHz, 27.12MHz and 40.68MHz (Fig 3). These frequencies are reserved specifically for use by Industrial, Scientific and Medical purposes (I.S.M.) to avoid possible interference with other users of the radio spectrum (i.e. broadcasting, satellites etc.). There are very good technical reasons why most companies in the field use the 27.12MHz band.

![Fig. 3. Working at 27.12 MHz is Safer and better moldable for a specific application as compared to Microwave Band.](image)

3. BARRIERS TO THE INTRODUCTION OF RF

Having spent the substantial years in this line of business, I believe that I am probably reasonably well qualified to venture an opinion on the relatively slow adoption this technology in the Food Industry. I would suggest that even today, most food industry technologists either have never heard of RF, or, if they have, they consider it as a last resort when all else fails. Why is this?

3.1. RF drying - a ‘Black Box’ Technology.

Strayfield supplies RF drying equipment to many industries.

In the Textile industry for example, dryers are used to dry bobbins of Textile yarn after the coloring (dyeing) process. The RF dryer was introduced into the textile Industry by Strayfield in the late 1970’s. Although this was much later than its original introduction into the food industry, RF textile drying has gained universal acceptance and is now the preferred method for drying over conventional hot air dryers.

For over 15 years now, textile people have asked us a very different question from that asked by the food industry. They ask not “how does it work?”, but rather, “what capacity RF dryer do I need and how much will it cost?” There are now well over 1000 RF textile dryers in China alone; several of our clients have over 20 dryers on the same site.

This is definitely not the case in the food industry. People who come into contact with RF appear to have a natural antipathy to using it.

Quite frequently this is due to either fear, ignorance or in some cases, a previous bad experience with a supplier who did not understand the RF technology properly. Purchasing the wrong machine usually results in problems with reliability, efficiency, and poor performance.

3.2. Microwave Heating

Microwave technology probably does not seem to fare quite as badly as RF in this respect. I believe that there are several important reasons for this.

3.2.1. Why do people opt for Microwaves in the first instance, instead of Radio Frequency?

Today, virtually every house, factory cafeteria, and convenience store has at least one microwave oven.

For many years, small Microwave ovens have been relatively inexpensive.

Typically today, a domestic microwave imported from China can easily be obtained off- the shelf for a very little more than a hundred dollars. Most manufacturers have at least one microwave oven in their R&D
facilities. Therefore, when food technologists are developing products it is natural to take some of the product, slap it in the microwave, switch on and “see what happens”!

If this very crude test shows signs of success, then the thought pattern goes - “OK – now I just need a bigger Microwave for the final process”. It is clearly a natural progression to consider a scale up, rather than to review the alternative, lower frequency option of RF little realizing the ill effects of microwave technology regarding uniformity of drying and reliability of equipment when scaled up to higher powers and sizes.

4. ADVANTAGES OF RF HEATING FOR FOOD PRODUCTS

4.1. A Unique Attribute of RF – the ability to profile Moistures
The free-running Triode Oscillator circuit can, if correctly designed, be dynamically matched to the load. The power absorbed by the load is automatically controlled by the itself. The RF dryer is uniquely suited to moisture control. It is able to profile the moisture content of the product passing through the dryer. If there is high moisture in the product, then more power is drawn automatically.

4.2. A solution for increased production where space is at a premium.
Many bakeries become ‘landlocked’. There is just no room to extend the conventional oven to increase production as the space at the end of the oven is already filled to capacity with coating, sandwiching or packaging equipment. RF can solve this problem, as we will see below.

4.3. A solution for improved product quality control.
One big problem especially in the biscuit industry is product checking (Fig 5). This occurs because of thermal stressing during cooling if the distribution of moisture is not even thru the entire mass substrate of the product. RF post baking drying equipment can address this issue, which can result in a dramatic reduction of rejects subsequently.

As RF heats the entire mass of the product from within simultaneously, the moisture level from end to end and the center of the product is very close. This is because the electromagnetic waves cluster together more wherever the moisture content is more as it poses lesser reluctance to their flow.
The exposure to RF energy in these areas increases and they heat faster than the surrounding areas. Hence this becomes an self regulating mechanism whereby at a microscopic level RF energy is distributed based on the moisture level in the product and in turn creating differential heating levels during the time of exposure to RF energy. Consequently this creates an even moisture profile in the product.

4.4. A solution for improved shelf life.

Generally when product moisture is mentioned it is the average moisture content in the product. This however necessarily does not mean that the moisture content is evenly distributed within the whole mass of the product. Say for example when a biscuit leaves the baking oven and is ready for being packed at 1% residual moisture, more often than not the center of the mass of the biscuit could have moisture levels between 3 to 4% and in some instances beyond 5%.

When such a packaged product is put thru the distribution system the product could sometimes wait for a month or two before it is consumed. We are all aware that higher residual moistures can lead to rapid growth of microorganisms, which in turn can render the product not consumable. As discussed above the the excellent impact of moisture profiling of a RF drying system can over come this problem very easily which in turn helps increase the shelf life over a non RF dried product.

4.5. A solution for cost savings.

The graph below (Fig.7) depicts a very standard drying attribute of extrinsic heating of any porous product that has moisture distributed throughout its mass. It is very clear from the graph that a big part of the energy is required to dry a very small amount of moisture. This is because the energy needs to flow from the outside to the inside in a laminar flow and in trying to do so has to encounter the thermal impedance of the product. Moreover a large part of the energy is also utilized to increase the temperature of the product. Another ill effect of extrinsic heating is that the surface may encounter higher temperatures than the core inside. This can sometimes be harmful to the product substrate.

![Power Cost Per Kg](Fig.6)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Power Cost Per Kg</th>
<th>Fuel Cost Per Kg</th>
<th>Labour Cost per Kg</th>
<th>Reduction in Total Costing by using RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.26</td>
<td>1.63</td>
<td>1.26</td>
<td>1.26</td>
</tr>
<tr>
<td>2</td>
<td>0.71</td>
<td>0.63</td>
<td>0.84</td>
<td>0.64</td>
</tr>
<tr>
<td>3</td>
<td>1.00</td>
<td>0.64</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>4</td>
<td>1.00</td>
<td>0.64</td>
<td>1.00</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Fig. 6. Sequence 1 is standard baking line without Radio Frequency Dryer. Sequence 2, 3 & 4 are lines working with RF as final Drying Zone. Sifting Drying Zone to RF Dryer reduces the overall costing for post baking of Food Products.

![RF Drying Curve vs. Conventional Curve](Fig.7)

60% of Total Drying Energy
RF Drying Curve
Conventional Drying Curve
40% Additional Energy Required without using RF Dryer.

Fig. 7. Energy Efficiency in Conventional w.r.t. varying Moisture content in a drying cycle.
These problems can be easily overcome with RF heating as the heat is generated intrinsically within the mass and that too within the water molecules that have a higher dielectric loss as compared to the surrounding substrate. This translates into a large reduction in energy required to remove the moisture at the final stages of drying and consequent cost savings (Fig.6).

5. APPLICATIONS IN THE FOOD INDUSTRY

5.1. Post Baking of Cookies and Crackers
The most well-known application for RF in the food industry is in Post-Baking of Biscuits (i.e. cookies and Crackers). In many cases where space is at a premium, and an increase in production throughput of 30% to 40% is required, whilst maintaining product quality, the only realistic option for many bakeries is to install an RF unit.

Uniform shapes can easily be processed in Monolayer. It has been determined from experience that more difficult irregular shapes benefit from reduced power density. This is usually achieved by packing more product under the electrode (typically forming a bed), so that although the power used remains the same, the residence time in the RF field is increased, thereby reducing the watts per product piece.

5.2. Drying Before Slicing
Many processes exist where bread is sliced following de-panning (removal from the metal baking pan). This is usually a discontinuous process whereby the loaves are taken off-line after baking and stored in huge conditioning rooms for 24 to 48 hours before they can be sliced. It has been shown that this labor-intensive activity can be completely eliminated by using RF drying to remove 2-4% of moisture, followed by reduced conditioning on a continuous accumulation conveyor. The point to make here is that the incorporation of RF into the line allows the size of the accumulation storage to become practically feasible and thus makes uninterrupted continuous processing possible. Without RF, the size of the accumulation storage required would be very large. This process has worked very well for several customers in Italy producing packaged, toasted bread, and also for customers processing Bagel Chips.
5.3. Pre-Heating of Yeast-based Doughs

Dough Proofing on a continuous basis usually requires a very long proofing oven in order to raise the temperature of the dough slowly to prevent the yeast culture being killed due to over-heating. This is because it is easy enough to heat the surface of the product, but the dough is a good insulator and so it takes a long time for the heat energy to penetrate to the centre of the product. RF rapid pre-heating, followed by a reduced length proofing tunnel to hold the temperature at 37 deg C (98 deg F) can accelerate this process and allows the length of the proofing tunnel to be reduced by up to 60%. This has been successfully implemented for a variety of products including Croissants, cake batters for Italian Panettone production, pretzel sticks and bread slabs (for breadcrumbs). In fact for breadcrumbs, good quality Japanese crumb can be manufactured using just RF energy alone.

5.4. Other Non-Bakery Food Applications
5.4.1. De-infestation of Walnuts and similar Products

RF heating has been demonstrated to be a proven alternative to banned chemicals like Methyl Bromide and Phosphine for de-infestation of post-harvest pests in nuts and similar products. The photo below shows the set up for a 3 month industrial scale RF trial on Walnuts undertaken jointly by WSU, University of California Davis, USDA Fresno and Strayfield at Diamond Walnuts in California. The results were excellent and showed a 100% mortality rate for even the most resistant insect pests. Similar work has been carried out at WSU and elsewhere on almonds and other related products.
5.4.2. In-Tube heating using RF Energy

Due to the unique ability of RF and Microwave energy to supply direct heat generated within the product, a field of opportunity opens up to be able to heat flowable or pumpable products within a tube. This concept has been successfully used to heat rice and also to fix dyestuffs onto textile fibers. The photos above show such a system under construction at our plant in the UK. There are limitations to this process, and the main one of these is the conductivity of the product. High conductivity limits the penetration depth of the energy and it has been found that products such as meat for deli products (which would be an ideal candidate) can only be processed either in solid form up to 1 inch diameter or in applications where meat in liquid is moved around within the tube.

Fig 11. RF Heating for Shurry Liquids.

6. HOW DO THE COSTS STACK UP?

Case Study #1 – North American Cracker Manufacturer

The diagram below (Fig.12) shows how a typical cookie or cracker line can benefit from the addition of RF drying. This is a typical North American cracker production line producing Saltine crackers. It can be seen that the introduction of an RF dryer at the end of the line makes it possible to increase the production rate from 2386 to 3340 kg/hour (which is an increase of 40%) without increasing the length of the line or any major modification to it apart from the obvious necessity to ensure adequate packaging capacity is available. The quality of the product is enhanced because the breakage or “checking” of the crackers is significantly reduced. This is impossible to achieve with any other technology. Lines like this have been installed in many of the major bakeries in the USA and around the world and have run well for over 30 years now. Therefore we can state with confidence that RF technology is definitely “proven and reliable”.

<table>
<thead>
<tr>
<th>CONVENTIONAL OVEN ZONES</th>
<th>RF Post Baking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven length 300 ft (48 inch band)</td>
<td>2.5%+</td>
</tr>
<tr>
<td>Production per hour 5250 lbs/hr</td>
<td>40% INCREASE</td>
</tr>
<tr>
<td>Oven length 300 ft plus 100kW of RF (21 feet)</td>
<td>With</td>
</tr>
<tr>
<td>Production per hour 7350 lbs/hr</td>
<td>No need to extend</td>
</tr>
</tbody>
</table>

Fig. 12. Graphical Representation Cracker Line of North American Manufacturer

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Case Study #2 – Indian Biscuit Manufacturer

Previously many Asian countries have shown relatively little interest in bakery products like cookies and crackers. However, the last few years has seen the market really start to take off, particularly in places like China and India as a more ‘western’ way of life has developed. Quality appears to be of lower importance in these markets, and the introduction of RF drying must usually be justified on cost alone. The self-explanatory Graph below (Fig.14) contains actual figures indicating the savings obtained by a customer in India for different high volume, low margin products.

It is also evident from the graphs (Fig.13) the excellent improvement of quality of the biscuits achieved due to moisture profiling yielding consistent output across the width of the oven. A good level of moisture profiling also helped reduce rejects by 1% on the overall production. This alone resulted in overall throughput increase of 14 to 15 tonnes of good quality biscuits per month per line.

![Graph](image_url)

**Fig. 13. Graphical Analysis/Comparison of Moisture Profiling across the band (With & Without RF Drying line)**
Cost Statistics of various Soft and Hard Cost incurred vs savings
By Using RF Dryer as post baking dryer for low margin biscuit line

<table>
<thead>
<tr>
<th>Power Cost Per</th>
<th>Fuel Cost Per</th>
<th>Labour Cost per</th>
<th>Reduction in Total Costing by</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.98</td>
<td>0.71</td>
<td>0.59</td>
<td>1.76</td>
</tr>
<tr>
<td>0.92</td>
<td>0.59</td>
<td>0.00</td>
<td>1.31</td>
</tr>
<tr>
<td>0.62</td>
<td></td>
<td></td>
<td>-0.80</td>
</tr>
</tbody>
</table>

Fig. 14. Figure indicated above are in INR (Indian Rupees). Line with 6 Minutes 50 seconds is standard initial (without RF in Line). Line with 4 Minutes 30 seconds is with a RF dryer inline with baking oven. Figures indicated in Blue Box are savings per Kilogram by use of RF Dryer.

Converting the Data in Tabular format we find the breakup as below.

<table>
<thead>
<tr>
<th>Semi- Sweet Biscuit</th>
<th>Without RF</th>
<th>With RF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(at 6 min 5 secs Bake Time)</td>
<td>(at 4 min 40 secs Bake Time)</td>
</tr>
<tr>
<td>Production</td>
<td>14.36 Tonnes</td>
<td>19.113 Tonnes</td>
</tr>
<tr>
<td>Monthly Production</td>
<td>1206 Tonnes</td>
<td>1605 Tonnes</td>
</tr>
<tr>
<td>Savings/month</td>
<td></td>
<td>USD 24877</td>
</tr>
<tr>
<td>Savings/year</td>
<td></td>
<td>USD 298,524</td>
</tr>
</tbody>
</table>

From the data given above it can be stated that the payback for the equipment is about 18 months.

7. CONCLUSIONS
Radio Frequency heating has acquired somewhat of a varied reputation over the years due to poor understanding of the process and poor design and implementation. However, with a proper equipment design, properly implemented, RF can be very successful indeed. With suitable products, the correct equipment and an experienced supplier, increased production, reduced costs and improved quality are easily attainable.

A second important point concerns how processes are developed: In the past, many companies and also scientific institutions have purchased small RF units and carried out research projects alone with little or no success. This happens because the R&D people are primarily food scientists and they do not properly understand the RF technology and how to solve RF related problems. Frequently such projects have been abandoned after a short while. I would advocate from experience that the only way to properly exploit this technology is for academics to work in close partnership with Equipment manufacturers and the end users.

Strayfield has several such partnerships which have worked to the advantage of both parties. Of particular note here is our partnership with Juming Tang and his team at WSU. The key ingredient for success here is that the arrangement must be a win-win situation for all parties concerned.