Mauritius Research Council

Post-Baling Drying of Biscuits

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Post-Baking Drying of Biscuits

By

Dr S. Oree (University of Mauritius)

P. R. Reetoo (Mauritius Biscuit Making Company Limited)

Funded By the Mauritius Research Council under the Private Sector Collaborative Research Grant (1999/2000)

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31/03/2000

TECHNICAL ABSTRACT

Industrial food processing techniques in general should guarantee an appropriate texture, colour and quality to the end product while maintaining a high yield and throughput. In Biscuit manufacturing, baking of the dough is most often accomplished in hot air ovens. Although this process is versatile and meets the requirements of colour and texture, it is slow, costly and has low yields.

In comparison, microwave cooking, a preferred food processing method in numerous cases, is more rapid and cost-effective, but is not suitable when browning of the product's surface is required.

The specific strengths of the two technologies can be combined in a process known as combination cooking. Hot air is used mainly for searing and browning the surface, while microwave energy is used to heat the interior. Such a strategy can result in significantly higher yields, improved quality and smaller system size.

1. PRELIMINARY STUDY

The project was effectively started in April 1999. During the first few months, work was carried out on several aspects of the application of microwave power in baking. The tasks carried out may be classified under three main headings :

(i) Literature survey of the use of microwaves and radio-frequencies in baking and post-baking operations.

(ii) Selection and purchase of basic experimental equipment.

(iii) Visit of production line and monitoring of some thermophysical parameters of the batter during cooking.

Literature survey.

A computerised search of relevant articles and monographies was conducted at the INIST data-base (French CNRS data-base) through the internet. The SYFED centre facility was used to order hard copies of the articles.

A copy of the PhD Thesis carried out at Bordeaux I University by Dr. R. Decourt for the "Lu Biscuit Company" was also requested from the author. This thesis titled "*Suivi de l'évolution des paramètres thermophysiques de produits pateux: Application à la pâte biscuitière au cours de sa cuisson*" gives important thermal and microwave absorption data for biscuits during their baking. The author follows the variation of the microwave absorption of a biscuit during baking and shows that the cooler regions are preferentially heated. His analysis also points out some distinct advantages of microwaves over HF post-baking. According to the author, microwave systems are less prone to electrical arcing, are more apt to operate at high temperatures and are more hygienic. The work has been used in the construction of a prototype tunnel-oven at the Jean Thève Research Centre of LU-DANONE situated at Athis Mons in 1998. The biscuits under consideration in his study was the "Petit Brun".

A number of products have been considered for microwave post-baking. In the case of cookies, Bernussi *et al.* have obtained significant reductions in moisture gradients and have completely eliminated cracking when using the combined microwave/hot air process. Willlyard reports that conventional cooking of hot-dog buns at 232°C for 4.5 minutes followed by 50 seconds of microwave treatment, was twice faster than conventional baking only. In a process like the baking of bread, where moisture must be conserved in the product, Ovadia reports poor results for the combined process when compared to conventional baking. These results illustrate that post-baking is more satisfactory for products that require low final moisture content as for example in the case of biscuits.

T.D. Clark estimates the gain in conveyor speed after addition of a post-baker can be in the region of 20 to 40% depending on the type of biscuits. This represents the percentage of the oven length used for final drying when the loft and crumb structure has already set. The post-baker takes over the task of removing the trapped moisture quickly and efficiently.

A list of references used for this work is given at the end of the document.

Equipment acquisition.

To test our different baking configurations, a microwave oven having a suitably high maximum emitted power was necessary. Moreover, other functionalities like variable average power output and timer control make things easier. Contrarily to our initial proposal, we have not selected a combined microwave/conventional oven, basically because most affordable models available are not designed operate beyond 250°C. Instead, the initial conventional baking will be carried out in a separate conventional oven (borrowed) before transfer into the post-baker.

The microwave appliance that was purchased is a Samsung M945 domestic oven having a maximum microwave output of 950 Watts which matched all the basic requirements while offering an excellent quality to cost ratio.

Another important instrument we acquired is a portable type K themocouple and display unit for on-site temperature measurement. The instrument covers the full range of oven temperatures encountered at the Subana factory and has an accuracy better than 3°C.

Monitoring of some thermophysical parameters of biscuits at M.B.M.C. Ltd.

We have followed the production of the "Give Me More" biscuits at the factory. Raw batter having a total initial moisture content of 13% on wet basis is molded into flat square shapes before input into a tunnel oven operated at a temperature setting of 260°C for a baking time of 8 to 9 minutes. The total length of the tunnel oven is 28 metres and it possesses two observation and sampling windows one-third (9.1m) and two-thirds (17.1m) through the oven. Because of high temperatures prevailing inside the oven, only the biscuits at the edges of the conveyor belt could be removed from the oven for measurement at the sampling points.

The internal temperature and weight of the accessible biscuits at different times during baking were recorded. The results obtained for these biscuits show that

(i) the dough's internal temperature rises very slowly at the beginning : i.e rising only to 33°C and 55°C respectively at the first and second sampling points in the oven from an initial 27 °C. When these biscuits emerge from the baking tunnel their internal temperature is close around 95 °C.

(ii) moisture loss is initially very low, but shows a marked increase during the closing stages of the baking process. A small amount of moisture is also lost after baking while the biscuits transit on the conveyor belt for cooling.

Since the biscuits near the middle axis of the oven are not accessible, laboratory experiments under similar baking times and temperatures have been carried out in a domestic conventional oven to obtain reliable data.

The mass of an average biscuit dough piece prior to baking is 14.75 g of which 1.92 g (13%) is moisture. The conventionally baked product has an average mass of 12.7 g and still contains about 1.00 g (7.9%) of water. This means that 0.92 g of moisture is removed in the baking process along with 1.13 g of other materials. Mass loss that is not attributable to moisture may be linked, at least partially, to the evaporation/ decomposition of fats and to the release of gases and flavours from the biscuits.

The figures given in this study at the factory must be taken with caution. They represent averages recorded on a limited number of biscuits taken at random on one particular day. Moreover, we have observed that the biscuits arranged near the sides of the conveyor, weighed about 0.6 grammes more than average. This is due to the fact that the oven is hotter near its central axis than at its sides. In fact, depending on the arrangement of a biscuit on the conveyor belt, the extent to which it is baked will present noticeable variations.

Moreover the oven temperature stated is the value that is displayed on the control panel. In fact, the actual temperature of the oven is non-uniform throughout the length of the tunnel and its average value is lower than the 260°C displayed.

The next step of the study will be to investigate the effect of various couples of baking time and temperature with microwave post-baking.

2. LABORATORY STUDY

In the second part of this work, the processes occuring during the baking and post-baking operations were studied at the University of Mauritius. In fact, several parameters that were difficult to control and monitor in the production line of the factory could be effectively followed at the University in domestic ovens. For example, at the factory it was impossible to observe visually the different stages of the baking process and to have reliable temperature measurements.

Dough composition and its transformation during baking.

The dough is a mixture of flours, sugar, milk powder, vegetable fats, water, syrup, raising agents and artificial flavours. As the mixture is kneaded to produce the dough, the flour proteins (gliadin and glutenin), combine to form a substance with chain-like molecules called gluten which determines the elasticity of the dough.

Then, during baking, the gluten network sets, and this setting, together with the gelatinization of the starch in the flour (at about 70°C), helps give the baked product its shape and rigidity. The product has an alveolar structure due to the simultaneous release of gases by the raising agents in the dough.

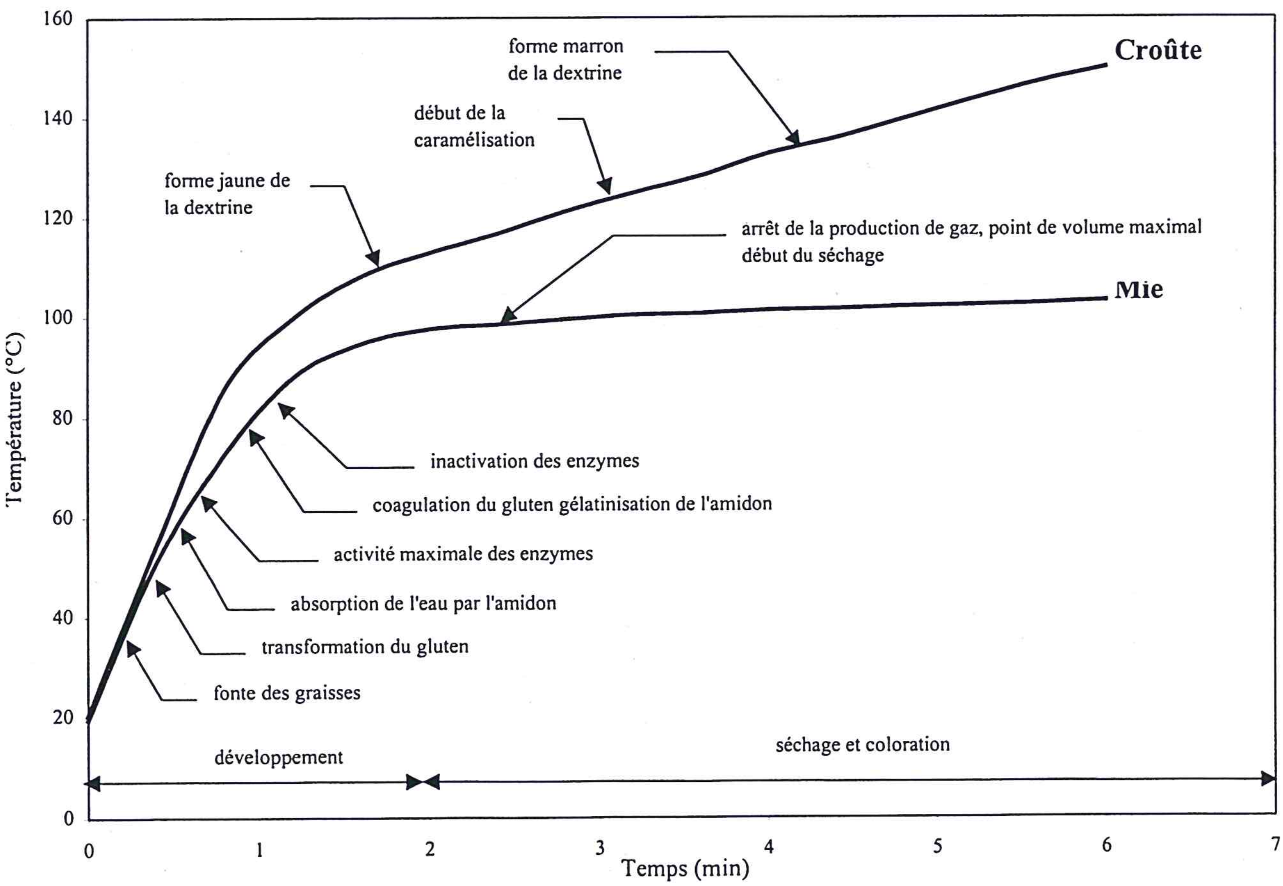

Fig. 1. Physico-chemical changes occurring during the baking of a sweet biscuit.

A flour's ability to form gluten is directly related to its protein content, so that baked goods that need a firm structure require a flour with large amounts of gluten. Flour with low gluten content is ideal for making tender products, such as crackers, biscuits and other quickbreads. At a later stage, reaction between reducing sugars and amino acids (known as Maillard's reaction) is responsible for the non-enzymatic browning of the surface of the biscuit.

Baking is also accompanied by evaporation of variable amounts of water depending on the baking conditions and the dough composition. It is important that most of the excess water be evaporated before the crust is completely formed in order to prevent cracks in the finished product.

A representation of physico-chemical changes occuring during the baking of a sweet biscuit is given in figure 1.

Microwave post-baking

One major objective in biscuit making is to reduce baking time without affecting the taste and texture of the product. In the past, two methods have been tried and implemented : Using forced convection and/or raising the temperature of the oven. However these techniques affect the product quality and are not particularly favoured by bakers. Since more than two decades, radiofrequency is being used with success in cutting down significantly production time and the energy bill per biscuit produced.

EXPERIMENTAL STUDY

Moisture content of the dough and of the finished product

The moisture content of the dough and the baked biscuits were measured experimentally by comparing the their initial mass and their mass after 48 hours treatment in a drying oven at 96°C. The results obtained are (on wet basis) :

Moisture content of dough =13 %

Moisture content of finished product =7.9 %

Study of the baking process

Baking of the biscuit dough was carried out a number of times with oven temperature settings of 190, 205, 217 and 230 °C. The temperatures were precise to ± 5 °C.

In these experiments, eight raw biscuits (initial mass = 118 ± 0.5 g) were regularly arranged on a fine metal grill and baked simultaneously in the conventional oven. The temperature was measured at the centre of the oven using a type K thermocouple placed about two cm above the level of the biscuits. Evolution of the external appearance, mass and temperature of the dough was recorded as a function of time by slight adaptations to the experiment.

Visual observations gathered over several experimental runs under diverse baking temperature settings all indicate the existence of two distinct phases.

There is an initial expansion phase: the dough expands, its surface becomes drier but it shows no change in colour. As soon as the dough has fully expanded, a second phase is initiated during which the surface starts to brown and the product becomes more firm. Baking was stopped when the correct crust colour was obtained and the samples were immediately prepared for post-baking in the microwave oven. The time duration of these phases depend on the oven temperature. These processes and their relation to temperature are studied in more detail in the next sections.

Biscuit dough raising phase.

The time taken for the dough to be fully raised is plotted against oven temperature setting. These results are based on observation and have an estimated error margin of ± 10 seconds. The duration of this dough raising phase decreases with increase in oven temperature.

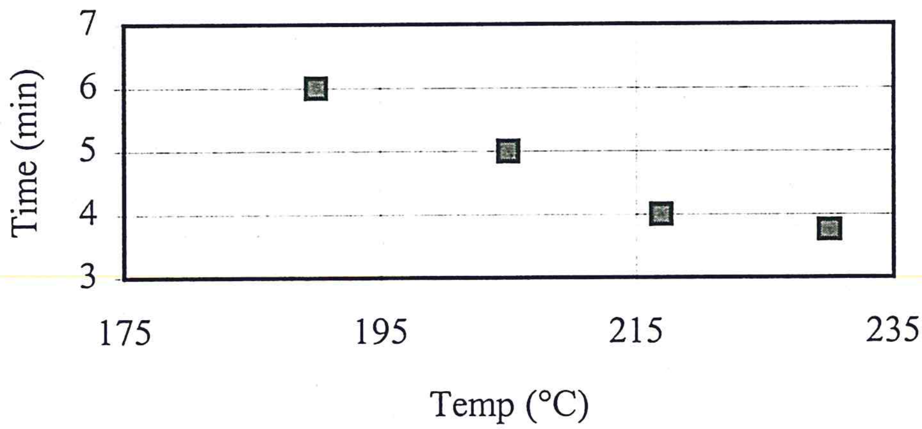

Fig. 2. Time taken by the biscuits to be fully raised at different oven temperatures.

Baking time.

The time taken for the correct crust colour to be reached is plotted against oven temperature setting. This is the *minimum baking time.* Here, the colour of a typical biscuit obtained from the factory was visually compared with that of the samples as they were baked to decide when to stop baking. Although it is simple in nature, this procedure gives reproducible results that agree to within ± 10 seconds over several experimental runs under identical conditions. The general trend observed is that the baking time decreases rapidly with increase in baking temperature. However, the time necessary for achieving the correct crust colour does not vary linearly with temperature .

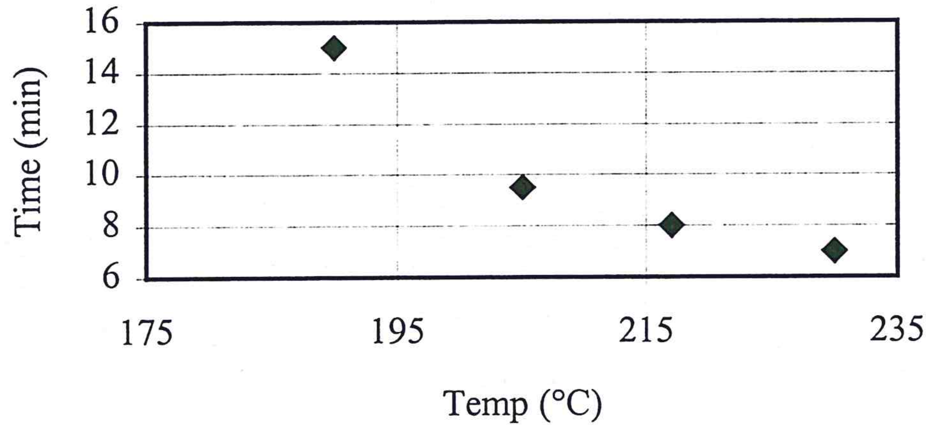

Fig. 3. Dependence of minimum baking time on temperature.

Mass loss during baking

Baking at higher temperatures resulted in a lower mass loss of the baked product at the end of the baking phase. Though the surface is fully baked, the interior of the dough retains a high moisture level. This is illustrated in the figure below.

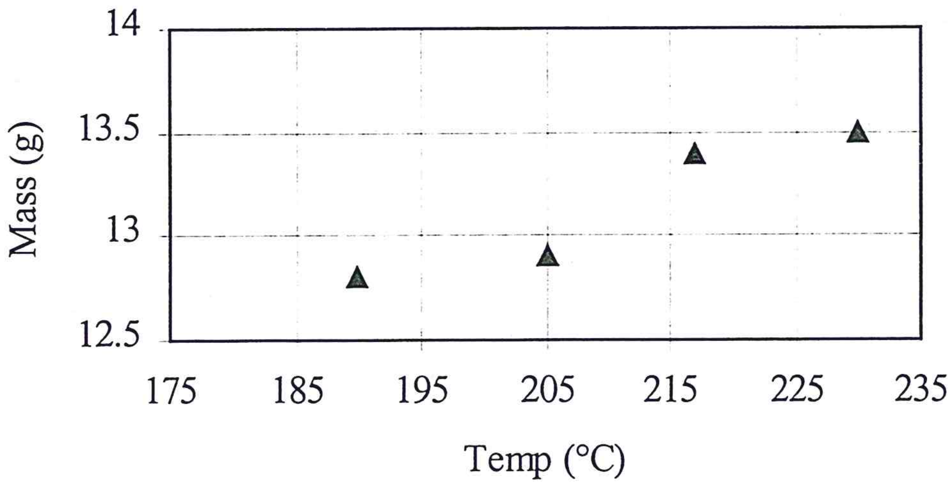

Fig. 4. Mass of biscuits at the end of the baking phase.

Variation of mass of individual biscuits during baking.

Eight raw biscuits of exactly the same weight (14.75 g) are carefully selected. Baking is performed in a conventional domestic oven at (220 ± 5) °C. A biscuit is taken away at intervals of one minute to be weighed. The mass of a biscuit in time can be obtained in this fashion.

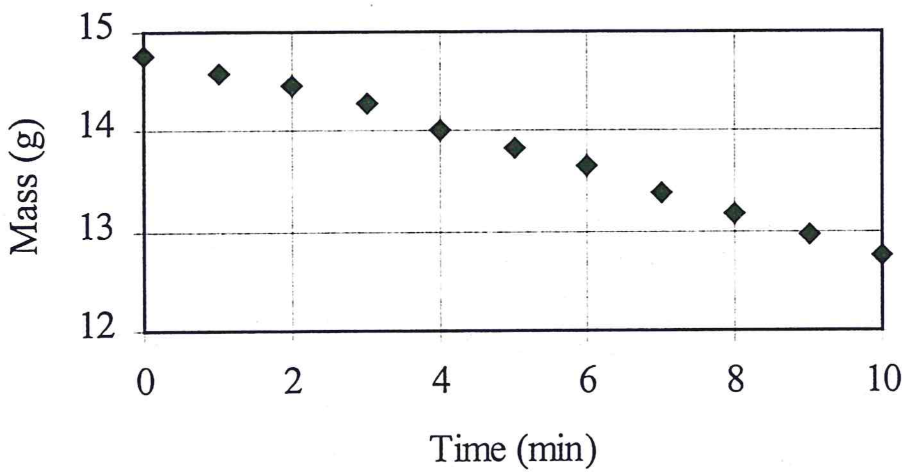

Fig. 5. Variation of mass of a biscuit during baking at 220°C

Internal temperature of the biscuits during baking

This parameter was followed by inserting a thermocouple probe in the middle of the biscuit prior to baking. The temperature of the oven was set at (220 ± 5) °C. Results obtained show that the temperature rise inside the dough is slow, especially around 100 °C where a slight plateau in the temperature curve is observed.

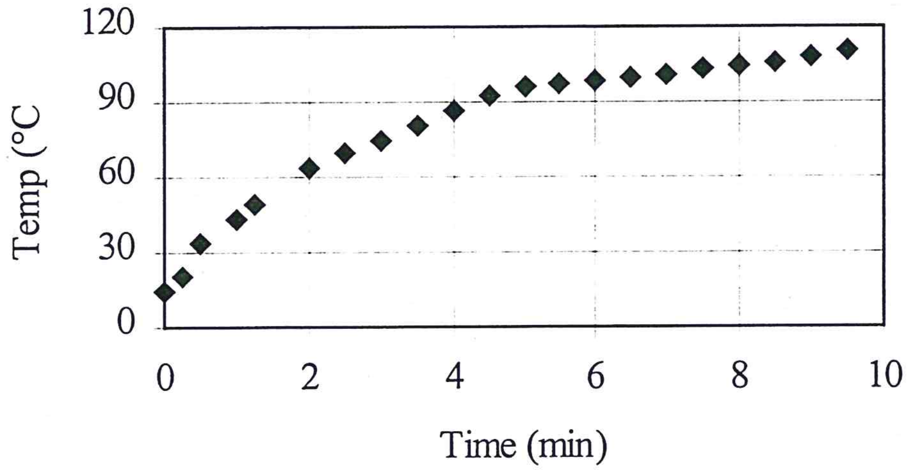

Fig. 6. Internal temperature of dough during conventional baking at 220 °C.

Mass loss during post-baking

After samples had been baked at 190, 205, 217 and 230°C respectively, microwave post baking is carried out. The total applied microwave power to a sample of eight biscuits was 950 watts. Mass loss of the samples during post-baking was five to ten times more rapid than during baking. The rate of moisture loss was also faster if the initial moisture content was high. Furthermore no surface cracking is observed during post-baking.

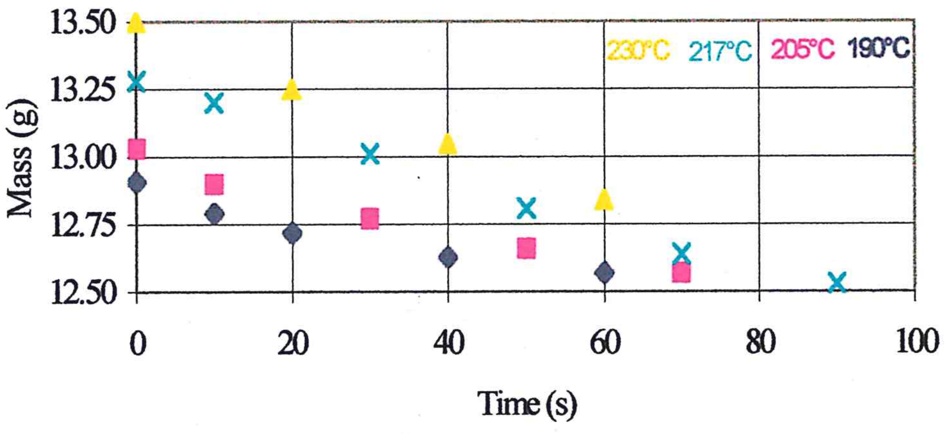

Fig. 7. Mass of biscuits during post-baking. Biscuits baked at different temperatures are represented with different colours and symbols.

Convection assisted baking

We also investigated the effect of forced convection on the quality of the biscuits. A batch of eight biscuits, each of mass 15 grammes, was baked in a convection oven operating at 245 ± 5°C.

This time, the browning of the biscuit surface started well before the end of the expansion phase of the dough. The dough was fully expanded after only 3 min 30 s whereas the colour of the biscuit crust was sufficient after 4 min 15 s. However, the crust colour was far from uniform and the corners of the biscuit showed signs of charring.

The average mass of a biscuit biscuit at this stage was 13.60 grammes showing that the centre had retained a high moisture level. The presence of cracks was also noted in about 50% of the biscuits. This indicates a very non-uniform moisture profile inside the biscuits. Post-baking in the microwave oven was subsequently carried out in the usual manner. The excess moisture was quickly and efficiently driven away.

Though it is accompanied by a significant reduction in the baking time, the use of forced convection in the baker does not seem a viable option because it also causes an inacceptable loss in product quality.

Conclusion

A small-scale experimental study has allowed us to demonstrate that post baking is efficient in removing moisture rapidly from the biscuits. The results will be useful in estimating productivity gains brought about by post baking. This aspect will be discussed in the final part of the report

3. DESIGN OF THE MICROWAVE POST-BAKER.

The microwave post baker can be seen as an applicator coupled to a microwave generator. A conveying system to move biscuits continuously into and out of the applicator should form part of the installation. In addition various functions and security features have to be implemented.

Construction materials

For the food industry, the build standard for microwave equipment is food quality stainless steel throughout, including the generator unit as well as the main applicator. The microwave cavity walls should in addition have very low magnetic losses (for example 304 or 316 stainless steels). The design of the applicator would be hygienic and fully hoseable in order to facilitate cleaning operations.

Adequate ventilation must be supplied inside the microwave applicator to prevent water vapour extracted from the biscuits from recondensing on the metallic wall surfaces. It is common practice to use punched sheets for the applicator body to enhance the evacuation of water vapour.

Conveyor belts would ideally be non-metallic to avoid electromagnetic field perturbations inside the applicator. Teflon-based conveyor mats, though expensive, are popular because of their resistance to high temperatures (300°C). In certain circumstances, carefully designed metallic belts may also be used.

Electric equipment

The microwave generator unit is normally distinct from the applicator section. Waveguides are used to bring the microwave power from the generator into the applicator. This is advantageous compared to RF post-bakers where the RF power is emitted from electrodes found inside the applicator itself. An equipment configuration where the generator and applicator are isolated not only guarantees better hygiene and safety but also shields the electrical parts from high temperatures and humidity. This contributes to extend the lifetime of the installation.

The main frequencies that are standard in industry are 896/915 MHz and 2450 MHz. Industrial magnetron microwave generators convert mains power to microwave energy with efficiencies of up to 75 percent at the lower frequency and up to 65 percent at 2450 MHz.

Generally for relatively low power applications (<5 kW) and where low capital cost is essential, 2450 MHz systems are preferred. Conversely in high power installations where electric power represents a significant portion of the running costs, an 896/915 MHz system would seem a plausible choice. However, economic constraints alone are not sufficient to select the more appropriate frequency: the type of process, the materials treated and operating conditions also come into play.

Because microwave magnetrons operate under high voltages, all electric cabinets should normally be of a fully waterproofed design to IP55 standard or better.

Limitation of stray leakage

Leakage levels from the applicator enclosure to the outside environment is subject to local regulations due to potential interference with wireless communications systems operating in the same frequency range. For example in the US, the maximum level of stray radiation due to 915 MHz systems is limited to 120 dBμV/m measured at a distance of 30 metres from the outside wall of the factory. European regulations are even more restrictive.

In conveyorized applicators, unacceptable levels of electromagnetic radiation may be transmitted to the environment through product entry and exit ports if the latter are not properly designed. This problem becomes more acute if these openings are of large dimensions compared to the wavelength. Two methods are usually employed to limit stray radiation.

The first method uses a half-wave choke at each opening to trap leaking radiation. Such chokes are, for example, implemented in most domestic microwave ovens. Recently, computer modelling has been used to enhance the performance of chokes. The second method uses end loads at the openings to absorb most of the stray microwaves. These two techniques can be used synergistically.

Arcing

The electric field set up in an applicator due to an applied electromagnetic wave is not uniform but varies from point to point in space, giving rise to a distribution of E-field minima and maxima. In a region of maximum electric field, the medium may become ionised if its breakdown voltage is exceeded. The breakdown voltage of dry air at atmospheric pressure is very high, but its value falls rapidly as the humidity content increases. Other factors affecting arc formation include the presence of dust particles, carbonised product and sharp metallic points inside the applicator.

Electric arcs can damage the generator or other parts of the post-baker and therefore care must be taken to prevent their occurrence. To decrease the risk of electric arc formation, the power density inside the applicator must be kept low ($< 40kW/m^3$). In other words, the applicator volume must be increased.

An electric arc may take several milliseconds to develop fully. If the arc is detected during the initial stages of its formation, fast security features present in some generators of recent design allow rapid shut down of the microwave power (within some 30 μs), hence preventing any damage.

4. ECONOMIC ANALYSIS

The strategy adopted for the first stage of this private sector collaborative research project was to establish the value of microwave post-baking on a single type of biscuit that is produced at the M.B.M.C. Ltd. *Give Me More Biscuits* seemed an ideal candidate for two reasons. Firstly, its presence in the local market is considerable and secondly, its thick shape retards the evacuation of internal moisture during hot air baking.

Subsequently, especially if the perspectives proved promising, other types of biscuits could be considered for the same type of treatment.

The market for *Give Me More* biscuits amounts to 4713 kgs monthly. At the factory in Bell Village, the production of *Give Me More* biscuits is normally scheduled in large batches. Each batch yields an average of 247.5 kgs of biscuits, which is equivalent to some 1300 packets of 190 grammes. The baking time of a batch in a stand-alone hot-air oven is 25 minutes. Therefore the rate of production of these biscuits is 10 kgs per minute.

Referring to the complete experimental data obtained at 220°C, we observe that the minimum baking time is 7m 45s. At this point, the mass of the biscuit is 13.30 g and a further 2 m 15 s are necessary to bring the overall moisture level to the target value of 12.7 grammes. We can estimate that approximately 25% of oven length are used to remove excess internal moisture from the biscuit.

Post-baking each biscuit from an initial mass of 13.30 g to 12.7 g in 1 minute would require a microwave power level of approximately 120 W per biscuit in our small-scale microwave oven. By scaling up these figures, it can be estimated that post-baking 800 biscuits (10 kgs) per minute under these conditions would require 90 kW of installed microwave power.

These figures obtained by such an extrapolation are in fact very high because the small-scale microwave appliance is not optimised. For example, due to the small load of the oven (8 biscuits) there is inevitably much power reflected back to the source. In an industrial microwave installation where all operating parameters are carefully optimised, the microwave power requirements could be considerably lower (up to 2 to 3 times lower) than this figure. A more realistic figure would be a 45 kW installation.

To get a better view of the impact of retrofitting a post-baker to the existing hot air tunnel, we will compare two scenarios:

(i) Biscuits are baked in a stand-alone conventional oven at 220°C.

Production rate:	10 kg per minute.
Conveyor speed:	2.8 metres per minute.
Total energy costs per kg biscuit:	**Rs1.20**

(of which Diesel represents Rs 0.33 and Electricity represents Rs: 0.87)

(ii) Biscuits are baked in the same conventional oven at 220°C for 7 m 45s followed by 1 min post-baking in an independent post-baker. The generator is supposed to convert 50 Hz ac to microwaves with 70 percent efficiency.

Production rate:	13 kg per minute
Conveyor speed:	3.6 metres per minute.
Energy cost for baking per kg:	Rs 0.93
Energy for post baking per kg (est.):	0.115 kWh
Energy cost for post baking (est.):	Rs 0.17 (*@ Rs 1.48 per kWh*)
Total energy cost per kg (est.)	**Rs 1.10**

From these projections, the most obvious consequence of adding a microwave post-baker to the existing baking unit would be an increase in the production capacity of around 29%. Interestingly, this increased productivity is not accompanied by an increase in power consumption per kg produced, but by a 9% decrease. However, these figures are estimates and more significant results will only be available after a prototype post-baker is tested.

Though an oven temperature of 220 °C has been used as a basis for our calculations, comparable percentage gains are expected for temperatures in its neighbourhood (within 20 °C).

6. CONCLUSION AND PERSPECTIVES

Both our technical and economic analysis have pointed out that microwave post-baking is a worthwhile option in the case of *Give Me More Biscuits*. The proven advantages of the proposed process over the conventional one, fully justifies persevering into the prototype stage of the project. This second phase of our research would provide critical information that will be invaluable in designing the full-scale post-baker. Another reason why this phase is so important is that the expected investments for retrofitting a hot air oven with a post-baker are considerable (several hundred thousand to a few million rupees). Several options have to be investigated at the prototype stage with minimum financial risk.

We have mentioned previously the non-consistency of the moisture content of the conventionally baked biscuits due to differing positions on the conveyor belt. Microwaves will preferentially heat up the moister regions and will certainly help in achieving a consistent moisture level in all biscuits. We also speculate, that microwave post-baking might lead to an improvement in biscuit quality, because of better retention of flavours resulting from a shorter exposure to the high temperatures in the oven. This aspect will need full investigation during the proposed second phase of this work.

The total monthly production of the Mauritius Biscuit Making Company Ltd is around 125 000 kgs which include several types of crackers. Eventually, several biscuit types could be considered for post-baking. This gives an idea of the potential for application of this technology at the Mauritius Biscuit Making Company Ltd.

We firmly believe that this research work should go through its second phase in order to assess fully its implications before moving into the full-scale development.

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