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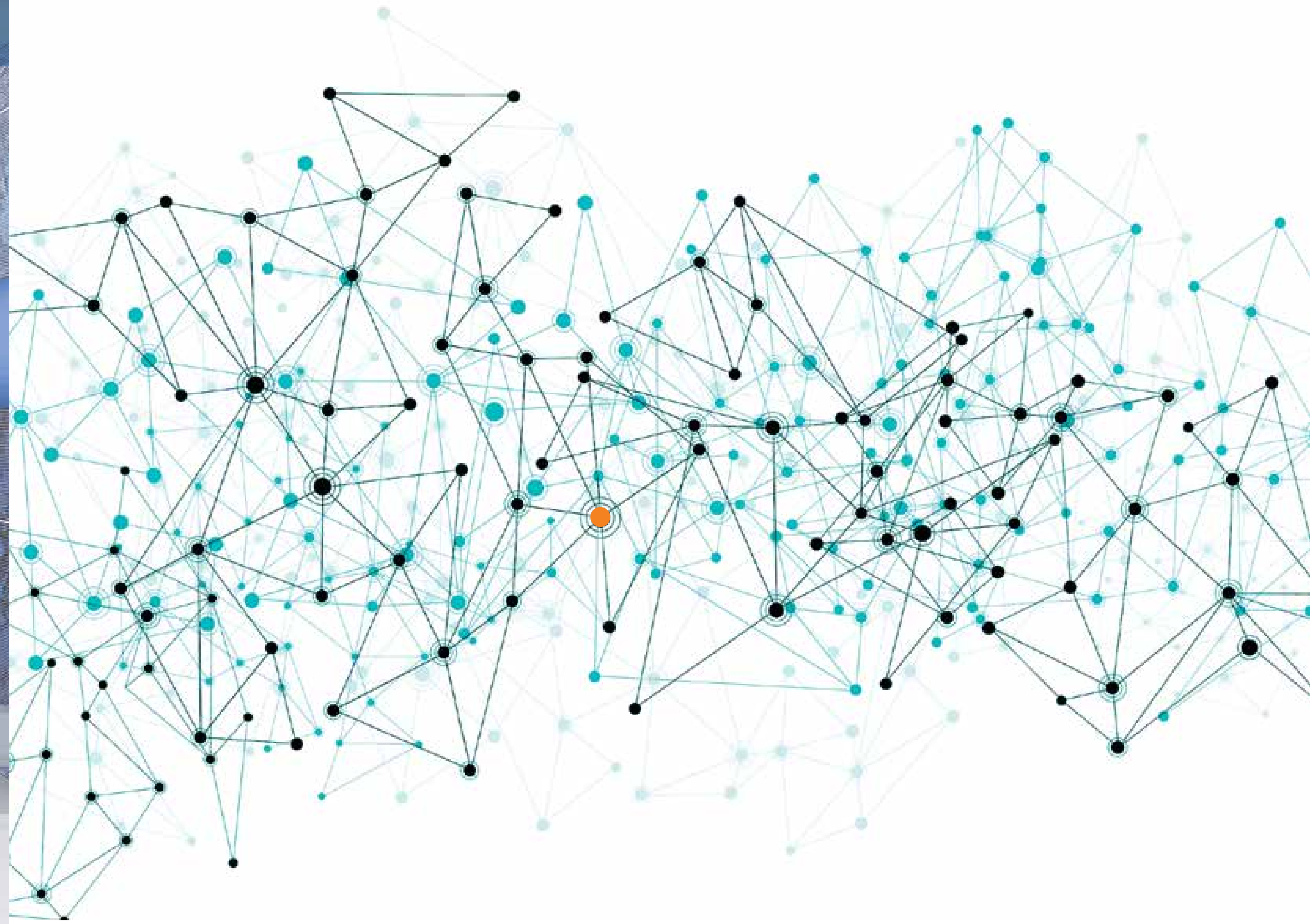
BAKERY TECHNOLOGY: RESEARCH AND INNOVATIONS



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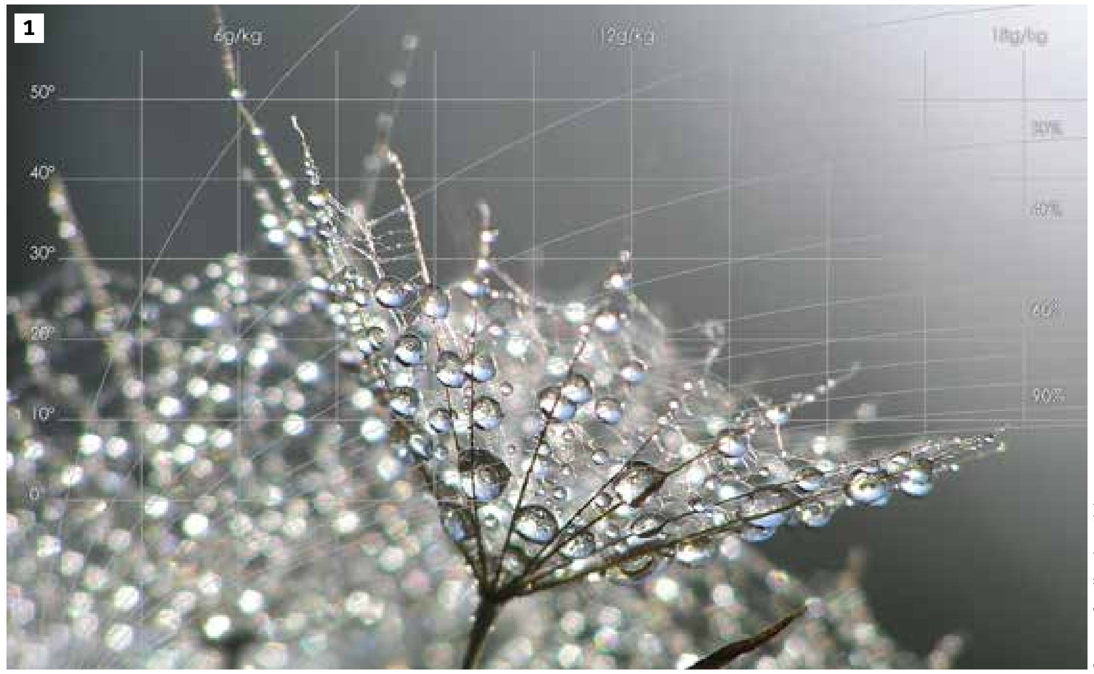
{ Translated from German into English }

Aerosols & bio-additives in the bakery

Insight into innovative ways to quality, shelf life and energy efficiency

++ The relationship between energy, hygiene and quality explained by an hx-diagram



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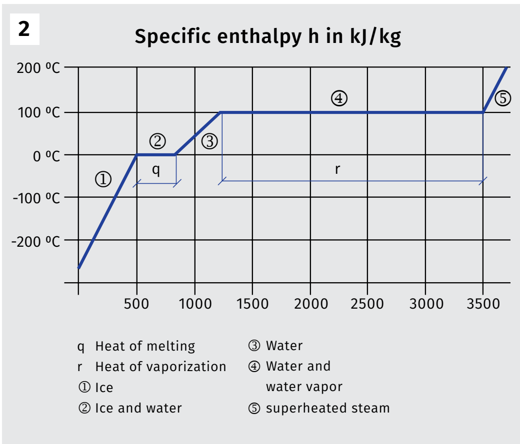
Traditional baking qualities and modern manufacture need not be a contradiction!

Within bakery process technology, products pass through temperatures that range from approx. –40°C to approx. +250°C and thus cover a very large span. The processes involved in this context comprise freezing, deep-freezing, cooling, heating and baking.

If we now look at the so-called temperature-enthalpy diagram of water (the main constituent of dough and baked products), the process steps mentioned above can, among other things, also be characterized energetically (fig 2). It is clear from this diagram that water at normal pressure freezes at 0°C (phase transition from liquid to solid, the so-called enthalpy of solidification) and, as long as a temperature of 0°C is maintained, does so until all the (freezable) water is frozen. Only then does a temperature reduction commence (deep freezing). During defrosting, the phase change (from solid to liquid) begins until the temperature has reached 0°C. Initially the temperature of 0°C remains constant (enthalpy of melting) until (all) the ice has been converted into the liquid state (water). The heat of melting (also called the melting enthalpy) needed for this is 333.5 kJ/kg.

This is exactly the same amount that is needed for example to heat cold water from a temperature of

++ Temperature-enthalpy diagram of water



0°C to +81°C. The conversion of hot water at a temperature of 100°C (boiling point) into steam at a temperature of 100°C needs 2257 kJ/kg (enthalpy of vaporization). Thus it is clear that the evaporation of water consumes approx. 6.7 times as much energy as the freezing of water. The conversion of cold water at a temperature of 0°C into steam at a temperature of 100°C needs 100 K * 4.19 kJ (kJ x K) + 2257 kJ/kg. In general the specific heat of vaporization of water is considerably larger than the specific heat of vaporization of other liquids. While water and water vapor (saturated/wet steam) coexist in region 4 (fig 2), the temperature does not increase until all the water has been evaporated.

This occurs, for example, when during the baking process, the core still has a temperature of approx. 100°C, but the surface of the baked product reaches a much higher temperature as a consequence due to the intense evaporation of water (crust formation) and approaches the surrounding temperature (i.e. baking temperature). The transition from steam to water (from phase 5 to phase 4 in fig 2) is similar to the vaporiztion at the beginning of a baking process. Under these conditions, superheated steam at, for instance, 130°C comes into contact with the surface of the dough piece, which has a temperature of approx. 35°C. As a result condensation occurs (steam turns into water), which on the one hand moistens the dough piece (keeping the surface elastic), on the other hand speeds up the transfer of heat into the dough piece. While this way, the dough is directly wetted with hot water at a temperature of 100°C, the heat of evaporation previously expended for vaporization is also released again in form of the identical amount of heat of condensation. Finally, these large amounts of energy ensure that starch can thermally hydrolyze on the surface and is converted into glossy dextrins (the baked product acquires its gloss). If the baker omits the use of steam during baking, the dough surface is moistened less or not at all, heat transfer is slower, and the amount of thermal energy is insufficient to cleave the glycosidic compounds of, for instance, starch: the baked product acquires a non-glossy, rustic appearance.

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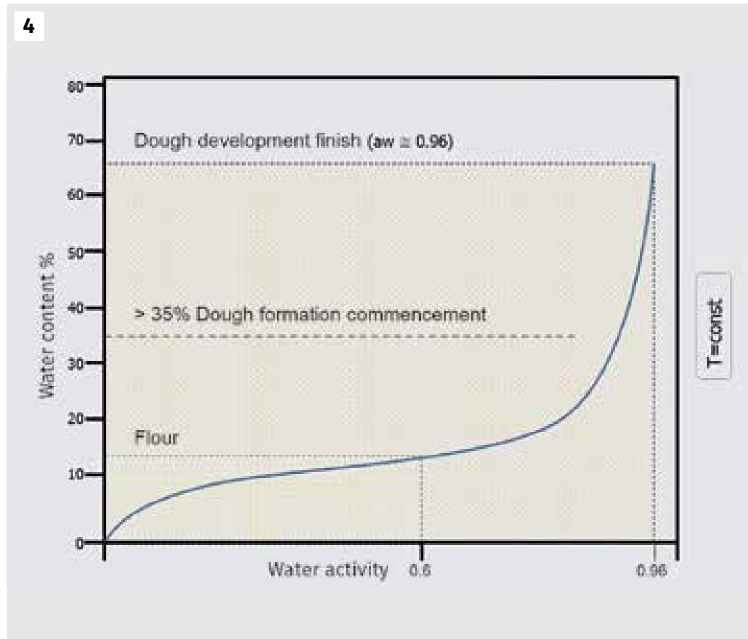
++ Hygienically controllable product conditioning before baking / freezing

While energy-related and other interrelationships, with the help of fig 2, may become clearer for our operational processes, the intent of the following climate technology considerations is to shed light on the fact that control over the atmosphere (temperature, humidity and pressure) is of paramount importance, especially in the bakery business. Focusing solely on the physical parameter "temperature" no longer is sufficient to achieve premium quality whilst operating in an energetically optimal way. Whereas experienced bakers have always taken into account the fact that dough needs to be treated differently according to the changing of weather conditions (so-called "artisan skill"), e.g. at times of high relative humidity and low relative humidity (RH),

++ Influence of the water uptake in flour on the water activity during dough formation and development (schematic, simplified)



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++ **Quality through consistent conditions**

there is still a lack of sufficient adapted machinery, methods and processes (fig 5) that are able to take such relationships into consideration.

These relationships become clearer when air with different levels of humidity-saturation is considered (fig 2). So, it is well known that clouds or mist have a relative humidity of 100% (people knowingly don't drown in it), whereas rain with its large water droplets has a relative humidity of approx. only 80%. This also refers indirectly to a thermodynamic parameter known and defined as water activity (a_w-value). While air humidity describes the amount of water vapor in the gaseous mixture of air (not taking into account liquid water), air, depending on temperature, is only able to absorb a certain amount of water vapor (a gas) (fig 1).

The most common measure of air humidity is relative humidity, specified as a percentage (%). It indicates the ratio between the instantaneous content of water vapor and the maximum possible water vapor content for the current temperature and pressure. It is contrasted by the so-called water activity of foodstuff (e.g. dough, fig 3), which defines the relative vapor pressure of water molecules of the respective product (e.g. headspace) relative to the vapor pressure of pure water.

Here, a scale from 0 (no water) to 1.0 (pure water) is used, whereas for relative humidity it is common to use a scale of 0 to 100%. The two measurements are equivalent to one another; roughly speaking, for example, a food with an a_w-value of 0.9 corresponds to a relative humidity of 90%.

If one considers the dough formation process according to the sorption of water (isotherm), dough formation starts at an a_w-value (of flour) of around 0.6 (fig 4). Subsequently, due to the water binding conditions during dough formation, the added water not only raises the water content in the dough, but also specifically the a_w-value. Whereas somewhat powdery properties still dominate up to a water content of 35%, actual dough formation does not begin until the proportion of water exceeds approx. 35%. Accordingly, the a_w-value initially rises rapidly, then only increases slightly at high water contents. At the end of the dough formation (fig 3), the a_w-value reaches approx. 0.96 (fig 4), which equates to a water content of, for example, 65%. If such a dough piece is brought into an environment of less than 96% relative humidity, desorption (drying out) and skin formation occur. For example, if a proofing chamber operates at a relative atmospheric humidity of approx. 80%, the dough pieces will lose mass with all the resulting consequences, including loss of thermal conductivity, loss of enzyme and yeast activity in the skin, to name just a few. From a technical viewpoint, this basically unfavorable occurrence is also undesirable because the resulting quality of the baked product becomes only sub-optimally controllable.

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One solution strategy to achieve optimized process management, e.g. for proofing or proofing control methods, lies in the use of so-called aerosols with additives. Aerosols, comparable to mist or clouds, are very small water droplets with, for instance, a diameter of 10µm, which look like steam, but are actually a free-floating mist that drifts easily (liquid water with very small droplets). Such aerosols can be produced by using ultrasonic generators (so-called piezo-ceramic converters). By using aerosols, it is possible to generate air humidity of up to 100%, which at last enable the proper handling of the dough pieces, because the a_w-value meets an appropriate relative air humidity, in this case, of 96%. Whereas aerosols, depending on the ultrasound frequency, yield very small droplets with a low sedimentation rate, water droplets at a size of approx. 150–250µm are equivalent to a rainfall and likewise show a high rate of fall (comparable to the formation of puddles in a proofing chamber/room).

The use of steam in proofing rooms/chambers at the usual temperature range of 30–35°C leads to (unwanted) condensation with droplet sizes that equate to the rainfall situation mentioned above ("stalactite caves"). By using aerosols for proofers, for instance, the baker is able to reduce the ambient air temperature to only 27–28°C, if the same fermentation time in comparison to electro-steamer is wanted. Consequently, as a rule the relative humidity, for instance in a proofing room, seldom exceeds 80% RH (depending on the amount of dough pieces), with all the results mentioned above (e.g. skin formation). Furthermore, hygiene risks arise in form of mold growth due to excessive condensation at the prevailing temperatures. Optimized climate technology, for instance, during the proofing interruption process (use of aerosols instead of steam), leads to an ideal equilibrium moisture content (avoidance of desorption, preservation of biochemical processes, maintenance of thermal conductivity, minimizing or avoidance of condensation, etc.). Subsequently, among other things the volume development of the baked products from dough pieces processed with corresponding climate control is more three-dimensional and the crust is thicker and more porous (better crispness, etc.).

Because aerosols are able to maintain a relative humidity (96% RH) appropriate to that of a dough piece (a_w-value of 0.96), desorption, for instance, can be prevented and gloss as well as windowing then occur comparatively equally on all sides: premium quality is possible.

If the processes are compared – aerosol technology vs. steam generator – it becomes clear immediately that a vaporization process represents the "expensive option" (fig 2). Measurements taken during a 20h-process (proofing interruption) confirm that an electrical vaporizer uses significantly more energy than an ultrasonic unit

++ **The removal of water from porous structures generates the glassy (vitreous) state (transition from rubber-like to the glassy state; T_g = Glass transition temperature**

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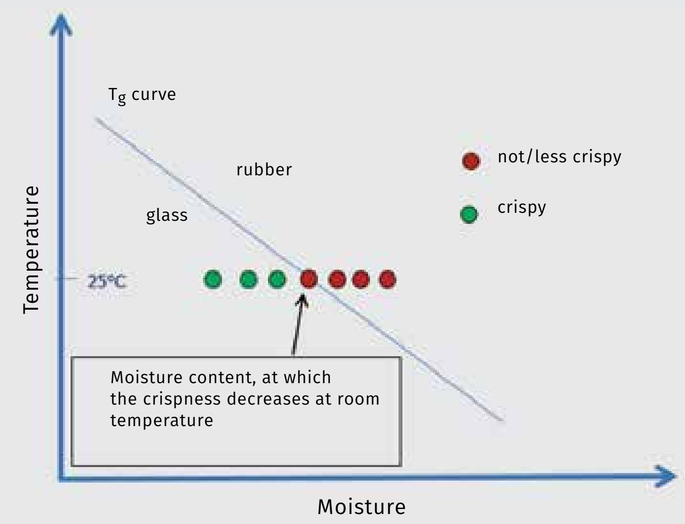
Crispy bread (Roudat et. al. 1998)



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++ Hygienic, biological air ventilation system outside the facility

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(including reverse osmosis) because there is no evaporation! The energy consumption by using the ultrasonic technology can be reduced by more than 35%.

Formation of crispness

Crispness is an important sensory attribute for many baked products (bread rolls, baguettes, flat baked products, etc.), which, unfortunately, generally lose this characteristic feature already within a few hours. In bakery technology, the production of crispness is currently achieved by measures such as extended baking, recipes with a higher proportion of malt, etc. On the other hand, it is also clear that crispness is characterized by the increased conversion of porous structures into what is called the glassy state.

The use of aerosols during the proofing process leads to crust structures that are distinctly more porous – gas bubble expansion is inhibited considerably less or not at all, because there is barely any desorption at the dough surface.

If baked products manufactured in this way are transferred into a vacuum cooler after baking, already the slightest water removal in the porous crust can cause brittle properties, which characterizes a typical crispness (fig 6). Under such conditions (vacuuming of open-pore crust structures), the crust can be converted to a greater extent into the so-called glassy state (dropping below the glass transition temperature Tg), with the result that the material property becomes much less vulnerable to subsequent hydration. In other words: a bread roll manufactured this way retains its crispness even when filled with cheese, sliced meat and/or salad over a period of at least 12–14h (currently 4–5h) at refrigeration temperatures.

For the first time, it is now possible to apply a process to retain the typical quality characteristics of many baked products for periods that are much longer than previously known. Even issues, such as hairline cracks in flat baked products, can be minimized or avoided altogether.

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++ Hygienic, biological air ventilation system inside the facility

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Cooling down baked products

Essentially, the cooling down of hot baked products represents a crucial step in the bakery operation (fig 3). The main concern is to ensure that the microbial-hygienic critical temperature range of approx. +65°C to +10°C is passed through as quickly as achievable, to avoid possible microbial recontamination (fig 9). Thus there are several reasons to apply a specific cooling process:

+ The requirement for sustainable slicing/cutting
+ The requirement for sustainable freezing
+ The avoidance of mass loss
+ The avoidance of the so-called flaking: preventing the crust splitting off the crumb in part-baked frozen products
+ The avoidance of hairline cracks, for example, in flat baked products, such as biscuits/cookies, waffles, crispbread, etc.
+ The avoidance of recontamination
+ And many more...

A novel approach to innovative process technology lies in the introduction of a certain kind of hygienic, adiabatic cooling. It utilizes evaporated cold that occurs when warm (dry) air is humidified. For example, an equipment operates in such way that it humidifies hot bread (95°C) with air-administered aerosols at 25°C (fig 9), so that cooling occurs concurrently. Warm process air at, for instance, 28°C is cooled down by air-administered aerosol moistening in a counterstream principle, to the direction in which the bread is transported, to further cool down (and humidify) baked bread. Instead of a continuous process, the same technology can also be used in a stationary process, whereby, depending on the objective, the cooling chamber can, additionally, be equipped with a cooling register, which in turn allows numerous optimized process designs.

Generally speaking, the use of this new technology (without active cooling, only evaporated cold) enables cutting the cooling time at least in half (in toast (fig 11), mixed flour and whole grain).

With the new technology, which operates with specific controlling of the ambient humidity (process-depending), weight loss hardly occurs (on the contrary, there may even be weight gain). The fact that in the case of packaged and pasteurized wholegrain bread, process-dependent mass loss occurs within the minimum 3 weeks shelf-life, is also of particular interest (fig 9). Room-cooled bread with an initial moisture content of 46.09% on the day of production, only measured

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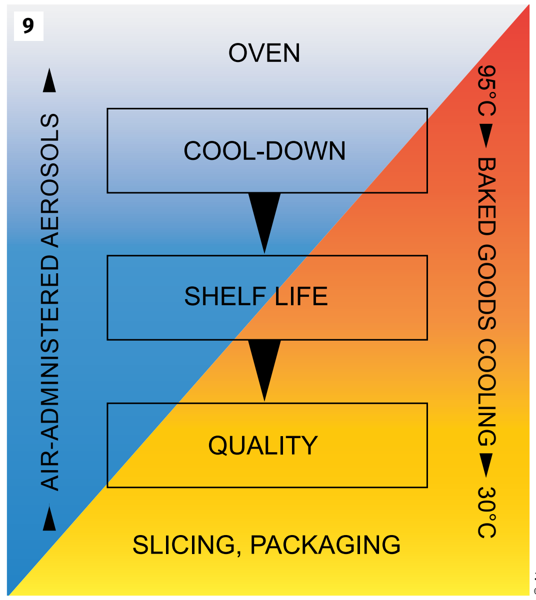

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++ Innovative, hygienic cooling tower principle

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++ The core temperature is amenable proportionally to the room temperature; 50% time saving when cooling with aerosols

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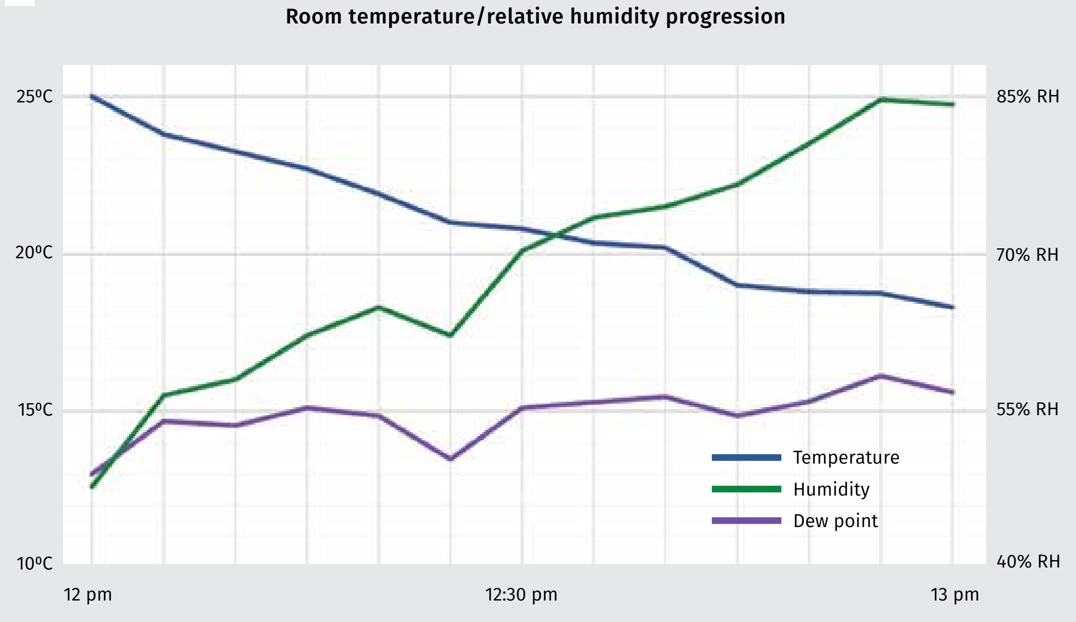

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40.98% after 3 weeks. When using optimized air-administered adiabatic cooling, a moisture content of 47.61% is measured on the day of production, and 44.20% after 3 weeks of storing. This means that the mass loss occurs at different levels depending on the process, but also at a varying degree. Thus wholegrain bread that is cooled down adiabatically loses more than 4% less moisture after a storage time of 3 weeks compared to those cooled down at room temperature (fig 9). Additionally, in newer applications, aerosols act as a carrier for natural antimicrobial and/or antifungal substances (plant extracts), prepared in the form of micelles. (Micellar means high bioavailability, it also means solubilizing insoluble substances, resulting in high efficacy at a low dose.) This is done to create a "clean-in-place" condition (hygiene in rooms/chambers/tunnels etc.), but also to decontaminate the product (baked goods) microbiologically, thus achieving an extended shelf life (inhibition of microbial growth such as mold, and more) (fig 12).

++ Specific, generated cooling curve, as it typically occurs in a first process phase

Flakey crust in part-baked frozen bread still remains a challenge to businesses. The causes are multifaceted and, among other things, a consequence of excessive dry cooling conditions prior to quick-freezing, whereby too high (hot) core temperatures are maintained. In fact, crust flaking off the crumb can be prevented entirely, if cooled down adiabatically (moist) prior to quick-freezing (fig 13). In addition, it is also possible to minimize brittle crust condition, whilst, at the same time, maintaining the lowest possible delta value of the temperature (the temperature of the hot baked goods relative to the freezer's surrounding temperature). Of course, the thicker the crust formation, the greater the danger of the crust flaking off the crumb. If frozen bread rolls are compared with regard to their quality characteristics, the differences are obvious. Namely, bread rolls without "moist" cooling (standard) are smaller in volume, show less windowing, poorer yield and also larger

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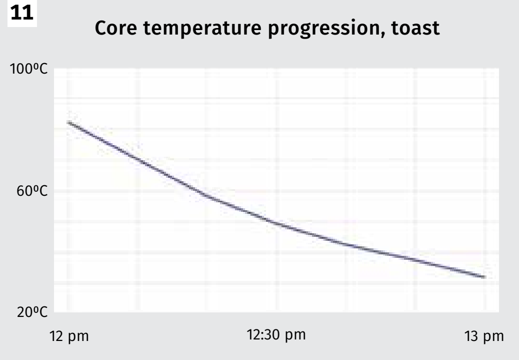

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++ Energy-optimized Hygienic Design

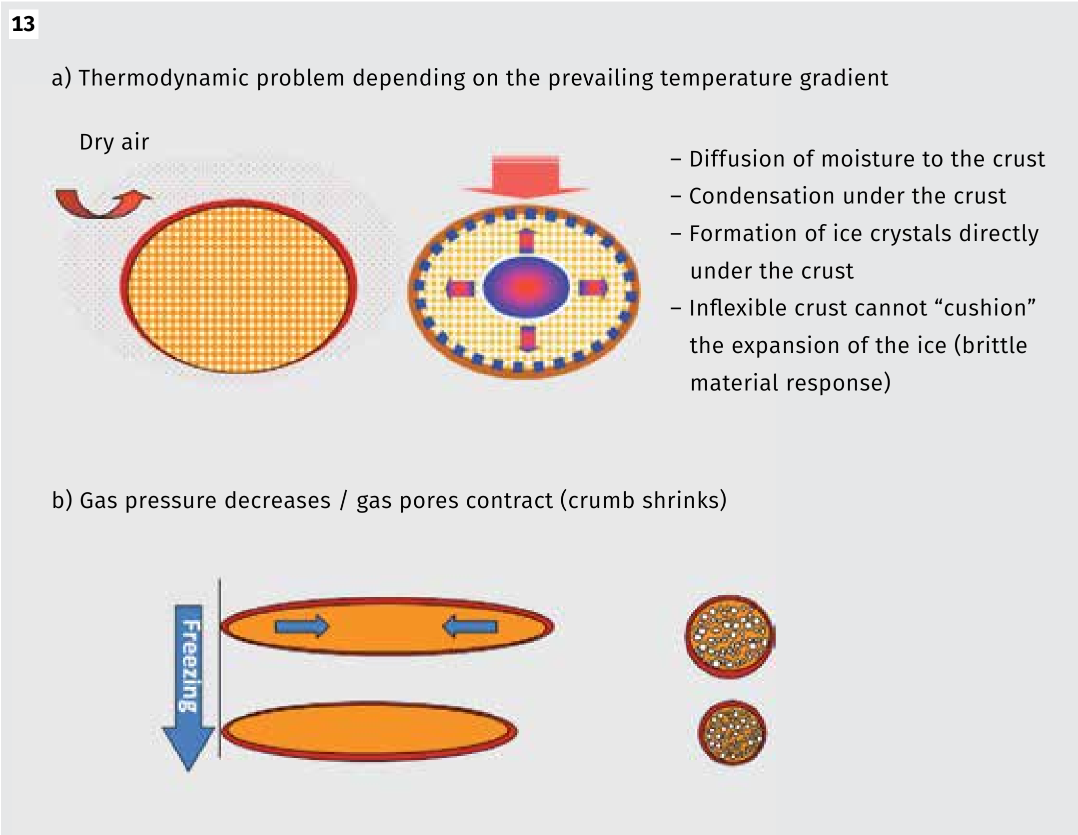
flaking-off rates. All of this can be improved by applying air-administered, ultrasonic aerosols, and flaking can practically be prevented.

Summary and conclusions

The process of evaporating water, energetically speaking, is expensive. Eliminating steam generation, for instance, in proofers and substituting it by applying aerosols (mist), leads to impressive energy savings (>30%). Likewise, in the case of proofing control methods for example, it is possible for the first time to maintain a relative ambient moisture level that corresponds to the dough piece (a_w-value: 0.96), if aerosols (mist) are used (96% relative humidity) instead of steam. Because mist, unlike steam, does not condensate, hygiene issues in proofers, for example (mold growth, cf. HACCP (Hazard Analysis and Critical Control Points)), are minimized considerably. If the a_w-value of dough pieces and the relative ambient humidity are held at a constant level (as much as possible) throughout the whole process operation (high equilibrium humidity), the highest quality characteristics for baked products are attainable (including crispness and the windowing pattern).

RESEARCH

++ Case study "Frozen baked products" by Le Bail (2006); the hypothesis of crust flaking off the crumb



Quelle: Prof. Le Bail (France)

Cooling and freezing baked products "today"

Problems	Causes
Freezer burn	High air speed
Drying out	Low ambient humidity
Weight loss	Drying out
High energy costs	Bad thermal conductivity
Crust flaking	Thermo-mechanical stress

The use of air-administered aerosols can also be utilized to intensify or prolong crispness. Here, vacuum packaging becomes particularly relevant for the porous crust structures (skin formation avoidance). Mechanical stress occurs in many baked products, when the climate conditions are not controlled (hairline cracks in biscuits/cookies, waffles, crispbreads, etc.). The use of the new technology offers effective relief.

RESEARCH

Attractive, new approaches also emerge for numerous unwanted issues in the cooling down of baked products. Among others, a positive influence can be exerted on both physical and microbial freshness retention. The undesirable flaking of the crust from the crumb in the case of frozen part-baked products can completely be avoided, if climate-controlled cooling-down technology is applied and the lowest possible core temperatures are adhered to before freezing (for example, 30°C, better still 20°C). Cooling-down time in the case of sliced bread can get shortened comparatively efficiently (fig 11) and the processes can be optimized in terms of energy and quality of the baked goods. At the same time, the hygienic aspect in the process is taken into account specifically (mitigating CCPs (Critical Control Points), extending the minimum shelf-life date.

The fact that mass loss resulting from the cooling-down process can be minimized or avoided altogether is of particular interest. In this context, the use of air-administered aerosols and the specific implementation of the above-mentioned relationship between the a_w-value and the relative humidity simply (and as complex as it may be) constitute the foundation for a ground-breaking (thermodynamic) process technology. Process steps downstream, like pasteurization or sterilization of sliced bread, for example, can now be realized with this new technology in a way that is gentle on the product and overall cost-effective in energy terms. Such a project-specific process is

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comparable in microbial safety with a comparable shelf-life at the very least, but clearly exceeds quality characteristics in the baked goods.

The fact that mass loss in packaged and pasteurized sliced bread can be controlled affects freshness preservation aspects and economic considerations alike. Potential savings of both time and energy, as well as improved product quality characteristics, are now accessible in an optimized form.

In summary, while aerosols have already found a variety of applications in the bakery for many years (mainly limited to proofing rooms and proofing control plants), the innovative approach of air-administered aerosols and biological additives will most certainly find more in the future. An intelligent use of climate-controlled process technology for the most varied applications offers unparalleled benefits for a bakery business in terms of time, energy, hygiene and quality. +++

Authors

Prof. Dr. Klaus Lösche
CEO, NFT GmbH
Johannisburgerstraße 20
27580 Bremerhaven
Germany

cell: +49 171 766 5511
office: +49 471 86014
email: k.loesche@icloud.com

Dipl. Ing. A.M.G. Reichenbach
CEO, Atmos Anlagenbau GmbH
Fichtenstraße 12
58640 Iserlohn
Germany

cell: +49 171 771 4219
office: +49 2371 944 677
email: amg.reichenbach@gmail.com

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