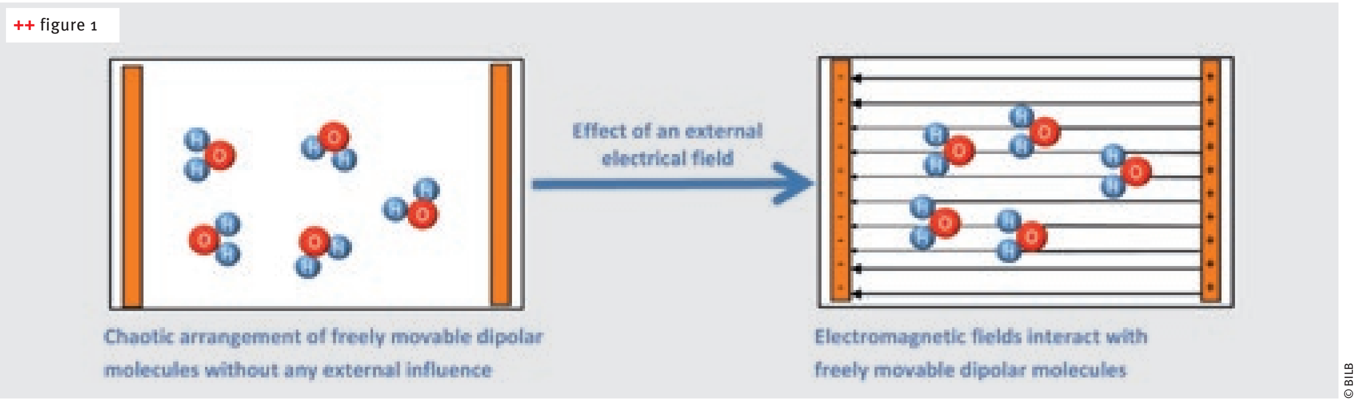
Using dielectric spectroscopy to measure dough consistency

RESEARCHERS HAVE DEVELOPED A NOVEL METHOD TO MEASURE DOUGH CONSISTENCY CONTINUOUSLY BY USING DIELECTRIC SPECTROSCOPY. THE SCIENTISTS TAKE A WENDEL MIXER AS AN EXAMPLE TO SHOW THAT THE MEASUREMENT METHOD HAS POTENTIAL



++ figure 1
The principle of dielectric orientation polarisation: Interactions between electric fields and a matrix with bipolar molecules (water)

The main primary constituent of dough is the natural product flour, which is subject to natural quality fluctuations depending, for example, on the cultivation method or climatic conditions. During the manufacture of doughs this gives rise, among other things, to varying rheological properties that can be detected and controlled only with difficulty [1]. If the rheological characteristic of a dough after the kneading process differs from its target specifications, this leads to considerable processing problems and quality fluctuations during downstream process steps (e.g. lamination). Thus an amount of added water that is not optimally matched to the individual flour quality can lead to "stubborn" or "shrinking" doughs [2]. In addition to recipe-dependent variables to generate optimally adjusted doughs, the kinetic energy introduced during the kneading process is of decisive importance for the production of the dough [3]. In this case the adjustable variables, namely kneading time, kneading tool geometry or kneading intensity, among others, result in complex interactions that lead to the development of the respective dough characteristics [4]. In particular the use of "intensive kneader systems", for example double wendel mixer systems, requires accurate control of the kneading parameters, because exceeding the optimum kneading time even slightly can cause over-kneading and thus irreversible damage to the dough.

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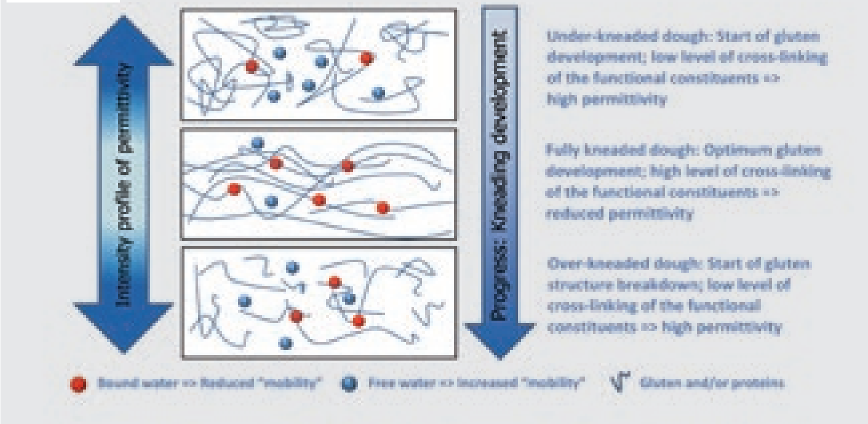
Visual and tactile impressions by experienced specialist staff are often very successful as an immediate assessment technique to ensure the consistent product quality of baked goods. However, these methods for judging the optimum dough properties are indirect and subjective. On the other hand a sufficiently specific measurement system for the in-line recording of dough properties that has proved successful in practical application does not exist. The use of process parameters such as dough temperature and/or dough warming or even the detection of the energy input as a way to control kneading time also usually yields unsatisfactory results. Kneading time control systems that make corresponding process parameters accessible based on direct dough consistency measurement, e.g. via strain gauges (SGs), have also been unsuccessful in the market. Although this technology enables a direct assessment of the dough during the kneading process, this sensor technology requires additional instruments in the kneading chamber, which significantly affects the kneader's geometry and thus also the results of kneading. The integration of additional tools in the kneading chamber also causes increased expenditure in the area of hygiene requirements [5].

Therefore the development of a measurement and control mechanism that continuously and accurately records and controls the rheological properties of a dough during the kneading process, and in addition does not require any modifications of the geometry in the kneading chamber, may represent a novel approach to minimize quality fluctuations during the manufacture of dough and baked goods [6; 7]. In

++ figure 2



++ figure 2
Dough structure formation during a kneading process as a function of water binding and permittivity during the course of the kneading time (diagrammatic illustration) and a matrix with bipolar molecules (water)

relation to this above-mentioned approach, a novel measurement method to characterize the rheological properties of wheat dough during a kneading process is being developed and tested in the context of a cooperation project funded by the German Central Innovation Program SME (Zentrales Innovationsprogramm Mittelstand, ZIM). This involves using a physical measurement method that detects the dielectric properties of dough during the kneading process. Considerable successes were recently demonstrated in the use of comparable measurement methods from the company Sequid GmbH, Bremen, Germany, based on dielectric spectroscopy to assess the quality of fresh and frozen fish, and to obtain information about the presence of water binding additives. In detail the method statistically evaluates interactions between the material to be examined and broad-band electromagnetic fields. By using multivariate analysis methods it is possible to obtain information about, among other things, the degree and nature of the water binding. This allows specific conclusions about the progress of dough structure formation as detectable by means of appropriate dielectric spectroscopy (measuring probes). By structurally integrating measurement probes of this kind into a double wendel mixer, it is possible for the first time to carry out continuous recording and determination of the dough structure formation.

Dielectric spectroscopy – permittivity

The application of dielectric spectroscopy as a measurement methodology to characterize the development of a dough during a kneading process is based primarily on the interactions between permanent dipoles and electric fields, whereby the totality of the substance-specific polar properties is described as permittivity. Water as a classic dipole, and/or media that contain water, e.g. dough, display particularly strongly pronounced interactions in this respect. If a medium with dielectric properties (dielectric) is placed between the plates of a plate capacitor and an electric field is applied, this leads to a change in the capacitance of the plate capacitor that depends on the dielectric properties of the medium.
At a molecular level, the applied electric field causes polarisation in the dielectric, whereby it is possible to distinguish between orientation polarisation and induced polarisation. Of particular significance in this respect is the orientation polarisation, in which the permanent electric dipoles (e.g. in H_2O) that are approximately randomly aligned in the absence of an electric field become spatially reoriented along the direction of the field (see fig. 1) [8].

In this respect the dynamic interactions between the applied electric field and the bipolar molecule matrix that is present form the basis of the measurement principle of dielectric spectroscopy. If in turn other interactions prevent the dielectric from aligning itself to follow the electric field, this has an effect on its permittivity. This occurs for example when binding interactions with other macromolecules restrict the "freedom of movement" of the bipolar water molecules. Equally, various partial aspects of the dough formation during a kneading process (starch swelling, gluten structure formation etc.) are associated at a molecular level with the attachment or binding of free water molecules to the corresponding macromolecules (see figure 2) [9]. ▶

++ **figure 3**
Diagrammatic construction of the dielectric measurement probe as exemplified by a dough scraper; dough scraper with integral measuring probe (green circuit boardon the picture in the middle); Diosna double wendel mixer system with built-in measuring probe

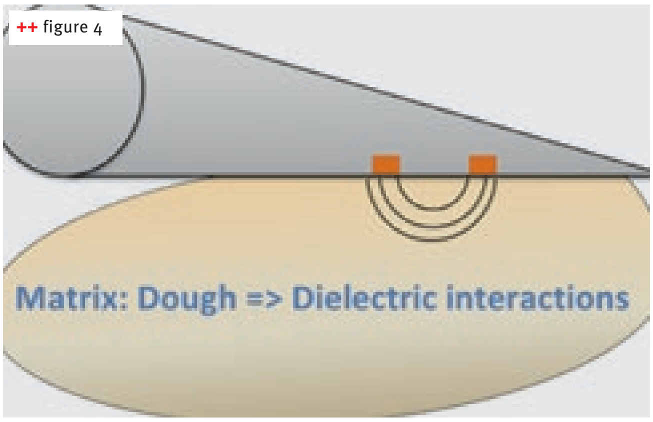
Due to the totality of the interactions described above, it is assumed that the detection of the dielectric properties of the dough may allow the establishment of a novel method that will enable the direct characterisation of the dough development during a kneading process as an inline measurement and control procedure. In addition to the actual detection of the dough permittivity and its characterisation as a function of kneading time, it is also necessary to develop the additional correlations that enable a description of the respective dough permittivity properties with the associated rheological and baking technological characteristics, so as to allow dielectric spectroscopy and its response variables to be used for the targeted generation of doughs with defined properties. In this way it is possible to use dielectric spectroscopy as a control technology to control kneading time as a function of raw material and/or flour qualities with the aim of achieving process-controlled dough consistency and/or dough quality.

Integration into mixing systems

In this respect the detection of the permittivity properties is not limited to the use of a classical plate capacitor, but can also be implemented via other measurement probe variants. One design solution that is appropriate for the project consists of using two electrical conductors, arranged parallel to one another, that can be integrated as a component of a scraper already present in the kneading chamber (see figure 3).

As shown in figure 3, the measuring probe is constructed in the form of two electrical conductors that are attached to the frame structure of the above-mentioned dough scraper before being sealed with Vulkolan. In addition the frame structure provides the precondition for integrating the signal cable without needing to modify the geometry of the bowl area or kneading chamber. The STDR-65 time domain reflectometer made by Sequid is used for the active part of the measuring system. A time domain reflectometer (TDR) consists essentially of a signal generator to produce voltage jumps with extremely short rise times, and a detector. For the present application, the voltage jump is carried via cables and the sensor's cable connection (see figure 3) to the sensor, where it is reflected back to the STDR-65 and is detected as a function of the dielectric properties of the dough. The dimensions of the STDR-65 that is used are only 208 mm × 168 mm × 55 mm, and due to its high stability against electromagnetic interference radiation it can be integrated directly into the kneader's housing.

The installation of the measuring probe in the lower part of the scraper ensures that it experiences a continuous incoming flow of the dough matrix that is to be characterised (see figure 4) and can thus record the change in the permittivity properties of the dough based on the radiated input of electromagnetic waves.



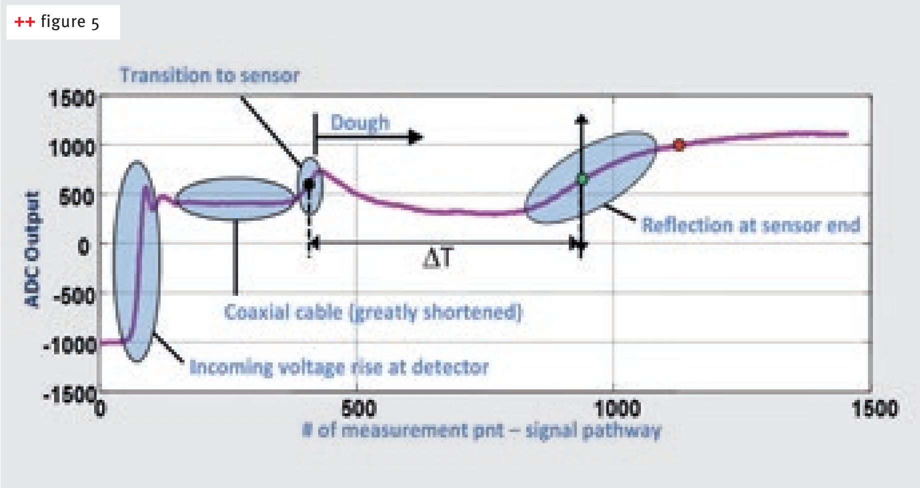
++ **figure 4**
Diagrammatic illustration of continuous dough characterisation by means of a dielectric measuring probe

Signal interpretation

In addition to the measuring probe already illustrated (in the kneading chamber or in the dough scraper), the entire measurement chain used to characterize the permittivity properties of the dough also comprises the signal cable (coaxial cable) needed to connect together the two modules.

Figure 5 shows the output of the analogue-digital converter (ADC) used in the detector as a function of time, in which each measurement point on the x axis basically corresponds to a time interval of 3.2 ps. The incoming voltage jump when it reaches the detector (ADC Output) is recognizable in the left-hand part of the figure. It is followed by the low-reflection region of the coaxial cable, shown here shortened, the transition to the sensor, and the interaction region which is essential for the evaluation. At the end of the sensor where it runs empty the voltage jump experiences total reflection, which is associated with a signal rise.

The signal changes between the positions "transition to sensor" and "reflection at sensor end" are especially important in this



source: Sequid GmbH

++ figure 5
Dielectric spectroscopy signal as a function of the measuring chain (TDR ····> Cable ····> Sensor)

respect. The description of the permittivity properties of the dough needs characteristic values that are able to describe the change in the permittivity properties of the dough during the course of the kneading time. Two empirically determined points are used for this purpose:

+ The turning point (inflection) of the signal profile at the end of the sensor (green)
+ The fixed point at the end of the sensor (red)

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