Process control for the food production

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Abstract In the following paper, measurements of shortcrust samples at different temperatures with high frequency electromagnetic waves are disclosed. Therefore, a vector network analyzer is used to generate high frequency signals. The samples were heated with a standard kitchen oven. Based on the measured signal parameters (magnitude and phase), the baking process can be characterized. Thereby a process control in baking operation is possible.

Keywords: Process control, radar, electromagnetic waves, dough, shortcrust, dielectric, transmission, inline measurements.

1 Introduction

The production of foodstuffs like bakery products or convenience food is even in a fully automated production line a critical task. Food is a natural product and based on the provenance, the weather conditions during the growth phase and the production process, the ingredients, the quality of the base products the final products variate in quality and consistence. It is the expertise of the people involved in the production process who are compensating these fluctuations inside the process-chain. Without the expertise of these bakers, brewers, confectioners and others who change the process minimal based on their expertise the quality of the final product will decrease considerable. However, even these experts have problems when changes inside the machine park influence the quality. The heating ramp of a backing oven can change depending on the age of the machine or the running time. The question is whether high frequency sensors can support this production process. When an electromagnetic wave transmits a dielectric material, the attenuation and the transition time of the wave are affected

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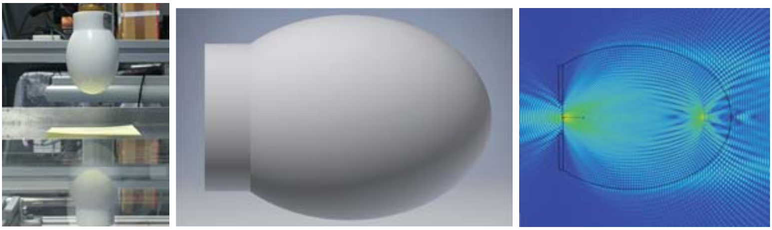
based on the dielectric constant of the material under investigation. In the microwave region the humidity inside the product normally dominates the behavior of the material, simplified a wet product attenuates the signal more and causes a greater delay than a dry product. But also smaller effects like the fermentation process of dough causes a detectable change. In this paper, we have a closer look on the baking process itself and investigate how the temperature profile influences products like cookies. The idea behind these measurements is not to control the temperature inside the oven but the speed of the production line. To fulfill this task, it is necessary to investigate the behavior of the dough during the baking process and to develop a measurement configuration, which allows us to measure inside the oven.

2 System concept

One of the main advantages of the microwave frequency range is the fact that electromagnetic waves in this frequency range penetrate the most non-conducting materials. This effect can be used to guide a signal, which is generated outside the oven through the isolating walls of the baking oven. Typically, the signals are guided by cables or metallic waveguide. For the measurements, a frequency-modulated continuous-wave radar (FMCW) is the best choice to perform the measurements. FMCW is a short-range measuring radar, which is normally used to determine the distance between the radar and an object. In this radar systems, a signal of a known frequency is generated which is modulated over a fixed period and varies up and down in frequency. A part of the transmitted signal is coupled out and compared with the received signal. Echoes from a target are then mixed with the transmitted signal to produce a beat signal, which will give the distance of the target after demodulation. Frequency difference between the received signal and the transmitted signal increases with delay, and hence with distance. The delay is not based only on the distance, a change of the propagation constant also creates a change of the measured distance. The water concentration typically dominates the value of the dielectric constant but during the baking several events occur that can be used to control the baking process. In a first step, it is necessary to check which of the events causes a dominant change in the dielectric constant in the microwave frequency range. The main challenge is that the reduction of the water concentration in the dough superimpose the smaller changes. The main events which typically occur during a baking process are the melting of the fats, the dying of the microorganisms, gases form and expand, sugar dissolves, proteins, including enzymes, coagulate, starches gelatinize, liquids evaporated, browning occurs on crust, changes occur to nutrients and pectin breaks down. Some of the events like the dying of microorganisms cause no relevant change of the dielectric constant in the microwave region. Others like gases which are formed or the evaporation of liquids cause a strong change of the dielectric constant and can be used to steer the baking process.

3 Measurements

The measurement setup for performing the dielectric measurements of attenuation and phase consists of a vector network analyzer for generating the electromagnetic waves in a given frequency range. The used VNA is able to generate frequencies up to 67 GHz. However, this frequency is too low for analyzation of the shortcrust. Therefore, two extender modules were used to generate frequencies in a range from 75 to 110 GHz. The investigated sample is measured in a transmission setup (see figure 5.1 a). In this, the electromagnetic waves of the given frequencies were emitted via a dielectric drop antenna through the sample and are received with another drop antenna on the backside of the sample. Due to the elliptical shape of the antenna a planar phase front directly behind the antenna is formed (see figure 5.1 b and c). Therefore, it is possible to arrange both antennae near to the sample. The antenna has a 3 dB-aperture of around 5 °. For the experiments, a simple shortcrust is used as sample. The shortcrust consists of three main ingredients: one part of sugar, two parts of fat, and three parts of flour. Margarine is used as a substitute for fat. The dough is rolled out to a thickness of 3 and 6 mm and cut into several squares (50x50 mm). Then the shortcrust samples were baked for 13 minutes (or 18 minutes for 6 mm cookies). Therefore, a standard kitchen oven with lower and upper heat mode was used. Every minute the dough was taken out of the oven and the transmission through the dough was measured in amplitude and phase over the complete frequency band from



(a) Transmission setup (b) Elliptical shaped antenna (c) Antenna field pattern

Figure 5.1: Measurement and antenna setup.

75 to 110 GHz. The measurement results of different same sized samples of the same manufacturing process show strong variation. Figure 5.2 exemplary shows the attenuation of 10 different shortcrust samples at a heating time of 7 minutes. Due to the strong inhomogeneity in the temperature distribution in the used oven, it cannot be guaranteed that every sample has the same temperature and this leads to different transmission behavior. Accordingly, multiple shortcrust samples were measured and the results are averaged. It should be noted, that for every measurement at a discrete time step of the heating process time a new set of shortcrust samples is assembled to reduce undesired effects of cooling and reheating of the samples. For the first view, measurements with different oven temperature and different sample thickness are done. The results are shown in figure 5.3, in the form of a relative attenuation with respect to the attenuation at time step t_0. The results are averaged over all sample measurements (as mentioned above) and over all frequencies too since there are no significant changes in the frequency range over time visible. An oven temperature of 150 °C and 200 °C is used. The curves show some characteristics. First the attenuation of the samples increase until a spot where the attenuation reaches a maximum value. From this point on the attenuation more or less linearly decreases until the attenuation later remains on a saturated level. This behavior is reproduced by several measurements. As mentioned above the dough consists of sugar, margarine and flour. The amount of water in margarine is about 20 %. By heating the dough, the water inside the dough is also heated. The dielectric losses of water

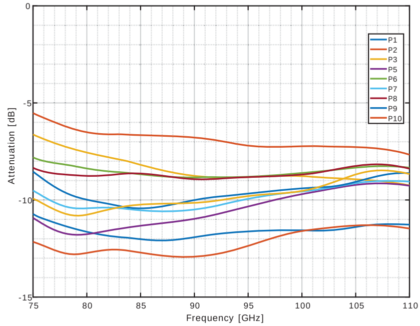
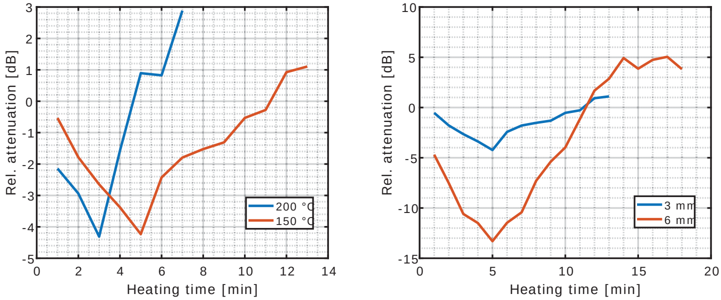


Figure 5.2: Measured attenuation of 10 different shortcrust samples at a time step.

increase with temperature [1] and the attenuation increases. This process is depicted in the measurement data. On the other hand the water evaporates due to the increasing temperature and at one point the attenuation decreases. In the measurement plot the increase in attenuation corresponds with a decrease of the curve (relative attenuation) and vice versa. During the series of measurements, it appeared that the dough samples were noticeably mushy at the beginning. Only from a temperature of about 90 °C, the dough pieces took a firmer structure. This temperature coincide with the measured dip in the attenuation curve. From this point on the outer structure of the samples becomes drier (from the outside to the inside) and the attenuation decreases. Figure 5.4 shows the surface temperature of the samples in the heating process. After a strong raise the temperature slowly reaches a level with a quite smaller raise. The dip in the curve for the experiments with an oven temperature of 150 °C is at 5 minutes. By increasing the temperature to 200 °C the dip moves to a shorter time (3 minutes). By increasing the temperature the described process is accelerated and the characteristic dip is reached faster. Increasing the thickness from 3 to 6 mm leads to a massive increase in attenuation, due to more mass of the sample. The dip does not change its position, at least not within the limits of 1-minute measurement quantization. The thickness of the sample seems to have a lower influence on the bounding water mechanism.



(a) 150 °C vs 200 °C (b) 3 mm vs 6 mm

Figure 5.3: Influence of heat and thickness variation on relative attenuation.

Besides the process of water getting free and evaporated, more processes take place. These are, amongst other things, the volume increase due to expanding gases in the shortcrust, denaturation of proteins and starch gelatinization [2]. To investigate these processes, further series of measurements with different dough compositions were carried out.

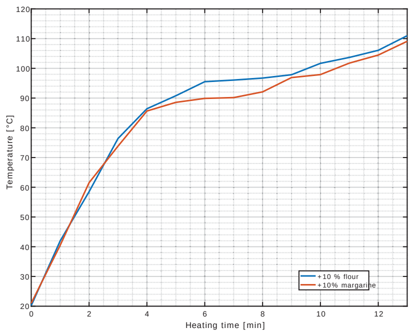
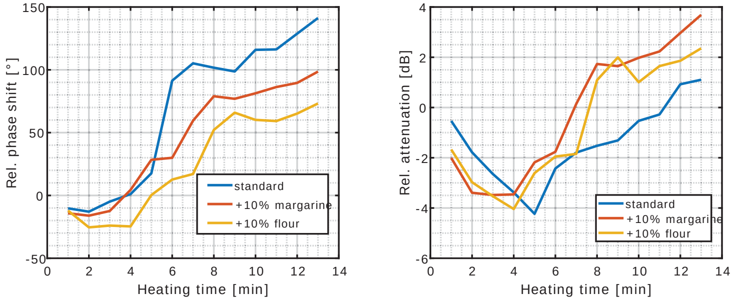


Figure 5.4: Surface temperature of dough pieces during heating process.

First, the amount of margarine is increased by 10 % and in another series the amount of flour is also increased by 10 %, to see the effects on the measured data (attenuation and phase shift). The results of these measurements are shown in figure 5.5. In the left plot of figure 5.5 the relative phase shifts (with respect to the shift at time step t_0) of the measurements are shown. In the first minutes the phase barely changes. The phase shift of an electromagnetic wave refers to a time delay, which is caused by longer transit time through a material. After around 4 minutes, the phase changes abruptly. After the beginning of heating the samples, the core temperature begins to increase more and more. This leads to an expansion of any gases that are inside the dough, for example air that has come into the dough by kneading. In the experiments, this expansion was observed after around 3-4 minutes. Due to the physical expansion of the samples, the phase abruptly changes. After the abrupt change, the phase constantly changes with a lower slope. By changing the composition of the shortcrust and adding more flour and margarine, the phase and attenuation results for flour and margarine look very similar. In contrast, the abrupt phase shift in the standard recipe is quite higher, the slope after has quite the same shape. The dip in attenuation curve occurs for the changed composition 1 minute prior to the standard composition. By adding more flour the dough becomes a higher contents of starch and proteins. Its shape is a little bit more brittle since the amount of water is less and the gelatinization process is more difficult. By adding more margarine the amount of water and fat increases. With increasing temperature the attenuation of fat generally increases, but the changes are not that high [3]. Regarding the measurement curves there are some visible effects by changing the composition of the dough. To make a more accurate statement of which processes have which influence on the transmission behavior, more measurements have to be performed, for example with more different compositions. In general, it should be noted that there are several points that affect the measurements. It has been found that the dough pieces do not all have the same transmission behavior due to manufacturing variations after production. This error is attempted to counteract by averaging the measured data. Furthermore, in the oven used, no constant nor uniform heat distribution can be ensured, so that the dough pieces do not all have the same temperature or temperature distribution. In addition, it can not be guaranteed that the dough pieces all have the same thickness, since the production was done by hand. All these sources of error influence the measurement and impede the interpretability.



(a) Relative Phase (b) Relative Attenuation

Figure 5.5: Measurement data for different dough compositions.

4 Summary

The results of the paper demonstrate that different events during the baking process can be observed in the microwave region by measuring the phase and amplitude behavior of a transmitted electromagnetic signal. These events are for example the volume increase due to expansion of gases, denaturation of proteins and starch gelatinization. The investigations have shown that a baking process can be mapped in the attenuation and phase behavior of electromagnetic waves. The measured curves show some characteristics that can be used for controlling the baking process and predict its completion. Typically the presence of water dominates the influence on the dielectric properties. To analyze the influence of the other processes several measurements with adapted compositions of dough were performed. The results between the standard prescription and the adapted prescriptions have similarities as well as differences. On the basis of the measurements carried out, however, no statement can yet be made as to which processes have which influence on the dielectric properties of shortcrust. It is necessary to perform more measurements to further specify the behavior of these influences.

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