On-line Monitoring of Yogurt Fermentation Using Ultrasonic Characteristics

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Abstract—Fermentation is the process where sugars are transformed into lactic acid. pH meters have traditionally been used for fermentation process monitoring based on acidity. Ultrasonic systems can provide a rapid, accurate, inexpensive, simple and non-destructive method to on-line assess and monitor the properties of food during process operations. This paper evaluates the use of ultrasonic measurements to characterize yogurt fermentation process by correlating acoustic properties and fermentation process characteristics. This research shows the correlation between fermentation time and acoustic attenuation as well as acoustic velocity. It also shows the effect of temperature on the received signal attenuation and velocity for yogurt and milk.

Keywords—Ultrasound; yogurt fermentation; sound attenuation; sound velocity

I. INTRODUCTION

Ultrasonic (US) sensors are proved to be effective in many industrial and medical applications. Most known are nondestructive testing (NDT) and ultrasonic imaging. Ultrasonic sensors are used as flow and level meters in process industry. Recently new fields of ultrasonic sensor technology have emerged, their importance is increasing. This development is partly boosted by improvements in transducer development and signal processing [1], [2], and [3]. Technology roadmap points out that ultrasonic will be among the emerging techniques that solve future problems in process control [4]. Ultrasonic characteristics are used for non-invasive process control by correlating sounds parameters and characterizing process parameters. One specific and challenging application is the analysis of liquid multi-phase mixtures like suspensions, emulsions and dispersions [5]. Ultrasonic sensor systems are used instead of industrial chemical sensor because of their fast response, robustness and reliability.

Sound velocity, sound absorption and acoustic impedance can be applied as acoustic properties together with advanced signal processing to measure liquid mixtures properties and to continuously control and monitor processes [6]. Ultrasonic measurement is based on the changed in the properties of the transmitted acoustic wave, which are influenced by the medium [7] as in shown in Fig. 1. Information that is needed to characterize the fluid media in time and space is contained in the transmitted or reflected ultrasonic waves [3]. This kind of measurement is considered as indirect method which makes it affected by other unwanted phenomena [3]. Ultrasonic sensors and their advantages, disadvantages and limitations of ultrasonic process are discussed in [8]. Henning describes the state of technology in the field of the computer-assisted ultrasonic transducer development and their limits [9].

![Fig. 1 Generic Ultrasonic System Block Diagram](image)

This paper verifies the use of the two basic sound parameters (velocity, attenuation) for yogurt fermentation process monitoring and control.

II. YOGURT FERMENTATION

The ultimate goal of this research is to automate the butter churning process using ultrasonic sensors which will improve the fermentation and churning process efficiency. Technological innovation is one of the drivers of increased payoffs for the dairy industry [10]. Ultrasonic systems are increasingly being used in the dairy industry. Butter has traditionally been made from yogurt. When a sufficient amount of milk has been collected, it is fermented then churned by shaking until butter granules are formed. Fermentation is the process where sugars are transformed into lactic acid. pH meter has been used for fermentation process monitoring based on acidity [11]. Extensive cleaning and calibration make pH measurement not preferred for on-line monitoring. Ultrasonic systems can provide a rapid, accurate,
inexpensive, simple and non-destructive method to on-line monitor the properties of foods during process operations. Ultrasonic is not an off-the-shelf technology. Thus it needs to be developed and scaled up for each application. Ultrasonic sensor systems can be utilized to continuously monitoring fermentation and churning processes to allow for inline control of the process. For example, ultrasonic sensor have the capability to replace pH sensor in fermentation process provided a correlation can be established to pH, conductivity and/or density values during the churning process. This can be implemented by utilizing artificial intelligence as well as digital signal processing techniques [12].

III. EXPERIMENTS AND MATERIALS

Two ultrasonic transducers have been used as transmitter and receiver as shown in Fig. 2. A 1 MHz 5-period burst has been generated (AWG 520, Sony Tektronics) and amplified to 10 V (AR 75A520, Amplifier Research) before transmitting it through the milk (transmitter: Olympus Panametrics V302, receiver: pico 1.2, Physical Acoustics Corp., Princeton, USA). Alignment has been performed with 3D stages (Newport). An oscilloscope (wavepro 700, LeCroy) has been used to obtain the time of flight which is the time taken by the ultrasonic pulse to travel through the milk. A double-jacket vessel contains the sample. Temperature has been maintained by a temperature controller with an accuracy of 0.1 K. A stirrer has been used for proper shaking and homogenization. Homogenized and fresh milk and plain yogurt were purchased from the local grocery store, Magdeburg, Germany. Raw milk has been provided by Wanke Agrar GmbH, Cobb, Germany. Plain yogurt was used as the yogurt starter culture. The fermentation has been performed with 400 cc of milk and 40 cc of yogurt starter at 40° C. The ultrasonic velocity was calculated dividing the distance between the transmitter and receiver transducer by the time of flight. The received ultrasonic peak to peak amplitude is measured by the oscilloscope. A pH probe (oMX 3000, WTW Weilheim, Germany) has been used for on-line measurement of yogurt acidity.

Fig. 2 Experimental setup

IV. RESULTS AND DISCUSSION

A. Acoustic Attenuation

Relative peak to peak amplitude is used to measure the change in the amplitude relative to the peak to peak amplitude at the beginning of fermentation process. Absolute attenuation is not used because it depends on many other factors. Relative peak to peak amplitude provides remarkable information for monitoring the change in yogurt fermentation process. Correlation was found between acoustic attenuation and the fermentation process as shown in Fig. 3. These findings can directly be used to model the yogurt fermentations process. The pH values determined during the fermentation process are shown in Fig. 4. pH decreases with fermentation as attenuation does. The slope of the attenuation is very similar to the slope of the relation of pH with fermentation time. Some distinct differences larger than the confidence range need further analysis. Hence, relative attenuation can be used to monitor the fermentation process as a replacement for pH measurement.

Care should be taken when measuring the amplitude of the received signal. An opposite relation could be measured if stirrer is used in high speed. We assume separation of water from milk although it could not be observed visually. Ultrasonic waves going through water should cause an ultrasound amplitude increase with the fermentation process as shown in Fig. 5 with the stirrer at high speed.

B. Acoustic Velocity

Relative time-of-flight is considered in this research with setting time-of-flight to zero at the beginning of the experiment. In this way uncertainties in alignment and effective distance between the transducers are compensated. Fig. 6 shows a remarkable correlation between the relative time of flight and the fermentation process. The time-of-flight measurements, however, have not been affected when stirrer is used at high speed. The ultrasound velocity increases with the fermentation process.

All the experimental results displayed in Fig. 3-6 are the average of a set of experiments under the same conditions. Moreover, when keeping the milk in a fridge below 10° C, we did not find a systematic tendency within several days.

C. Discussion

Our first steps toward a real-time, on-line, non-contact monitor of the fermentation process with ultrasound have shown an adequate relation between attenuation and speed of sound with fermentation time. Both acoustic characteristics can therefore be used to monitor the fermentation process. However, the difference in the amplitude between the start and the end of fermentation is quite bigger and smoother than the time of flight. The second advantage of the amplitude measurement is that it does not depend on the temperature as shown in Fig. 7, whereas Fig. 8 shows an effect of temperature on sound speed of yogurt and milk.
Fig. 3 Relation between amplitude of the received signal and fermentation time. Amplitude decreases with the fermentation time.

Fig. 4 pH measured using a pH meter. pH decreases with fermentation.

Fig. 5 Relation between amplitude of the received signal and fermentation time when stirrer is used. Amplitude increases with the fermentation time.

Fig. 6 Relation between relative time of flight and fermentation time.

Fig. 7 Temperature effect on the received signal attenuation for yogurt and milk.

Fig. 8 Temperature effect on the sound speed of yogurt and milk.
V. CONCLUSIONS AND FUTURE WORKS

Fermentation is the conversion of lactose to lactic acid by bacteria. When milk is fermented to make yogurt, its elasticity increases accordingly. Relative amplitude attenuation and time of ultrasonic flight is measured during fermentation process. Correlation was found between acoustic characteristics and the fermentation process. During the fermentation, acoustic attenuation and velocity change due to the change in the nature of the crossed middle. Results showed that relative ultrasonic measurements (velocity and attenuation) can be used to characterize yogurt fermentation process. The amplitude measurement is less dependent on temperature than ultrasonic velocity measurement. Stirring at high speed can have a big effect on the ultrasonic measurement of fermentation process; we assume separation of water and milk whereas air bubbles are much less likely. This finding has to be considered for future work, where ultrasonic measurement will be evaluated for butter churning process which requires stirring.

References