Rapid Ultrasonic Milk Analyzer for the Indian Market

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Abstract: ***The high sensitivity of ultrasonic parameters to composition and state of milk and other liquid food products is now well established. Multiple informative ultrasonic parameters can be measured: sound velocity and acoustic impedance, as well as their temperature slope, which are sensitive to compressibility, density, and hydrophobicity of the sample; and ultrasonic absorption and reflection, as well as their frequency slope, which are sensitive to size of the particles and to relaxation processes due to energy losses, aggregation, or conformational transitions. The first application of ultrasound for quality control of milk started about 50 years ago in evaluation of fat content. Currently available commercial ultrasonic devices include measurements of the acoustic properties of milk at different temperatures and therefore require waiting for temperature equilibration of the milk when the sample is heated or cooled and cannot be used for real-time monitoring. In this paper an ultrasonic analyzer that uses radially oscillating PZT piezoceramic tubes, and is applied for monitoring of fat globules, solid-non-fat (SNF), and protein of raw milk in cowsheds is described. This device employs high-intensity standing waves for preliminary separation of the fat globules and SNF by the acoustic radiation forces and employs low-intensity standing waves for compositional analysis. A device based on standing cylindrical waves is far superior to other ultrasonic instrumentation in respect to industrial requirements such as cost, precision, and ease of use in flow-through systems. Preliminary testing of the analyzer was carried out on milk samples from five cows milked twice a day for one month. More than 300 samples of the raw milk were tested. Obtained results demonstrate a possibility of rapid measurements (5-10s) and good correlation with the central certified laboratory for milk quality testing run by the Cattle Breeding Association. Continuous monitoring of milk fat, protein, SNF, which typically have high day-to-day variation, provide a much-needed tool for dairy management and for veterinary diagnostic purposes. It was found that milk production level, stage of lactation, and outside temperature have significant influences on milk composition. The technology can be incorporated in either a hand-held portable device or as an added on-line unit in existing flow-through systems. This will enable continuous on-line monitoring of the quality of milk, and will facilitate the prediction of mastitis by the determination of the main components with the following accuracy: fat (±0.05%), protein (±0.05%), and SNF (±0.05%). At a later stage the ultrasonic milk analyzer will be applied to compositional analysis and quality control in different liquid milk products.***

Keywords: milk quality, ultrasonic monitoring, cylindrical standing waves, acoustic radiation forces, fat-SNF separation

1. Introduction

World milk production is estimated at over 600 million tons and is increasing, particularly in India, the world's largest producer and consumer, where annual milk production is approximately 135 million tons. There are about 120 million cows & buffalos in India and there is a long tradition of milk production and a tradition of selling fresh milk over the counter in the street. Food safety and food security are very much on top of the agenda in India, but despite these facts, the milk industry in India does not possess a capability to measure and check the milk quality in a cheap and efficient manner.

More than ten million dairy farmers belong to 120,000 local dairy cooperatives. They sell their product to one of 170 milk producers, cooperative unions which, in turn are supported by fifteen state cooperative milk marketing federations. Further, there are a similar number of non-cooperative milk collection centers as state cooperative milk marketing federations. In India the market is characterized by small farms in poor rural areas, which suffer from relatively large reject amounts. In India, yields per cow are less than one-fifth those of foreign producers, primarily because of the low health levels of the livestock and feed quality.

In this paper an ultrasonic analyzer using cylindrical waves, targeting Indian farmers and dairies, is applied for monitoring of fat globules, solids-non-fat (SNF), and protein of raw milk. This device employs high-intensity standing waves for preliminary separation of the fat globules and SNF by the acoustic radiation forces, and employs low-intensity standing waves for compositional analysis, and is far superior to other measurement instrumentation in respect to industrial requirements such as cost, time of analysis, and precision. The ultrasonic analyzer can offer a solution for a simple farming operation or for a fully automated milking station using robotics. The Indian market is attractive because of its size and the need for a cheap and efficient solution, which can be provided by the ultrasonic analyzer.

By applying ultrasonic technology at the collection dairy, the Indian market will receive the following benefits:

- Payment can be calculated in real time, thus allowing the farmer to be paid immediately;
- Water can no longer be added secretively to increase quantity;
- Milk from diseased cows will be detected in real time.

2. Ultrasonic Standing Wave Resonator

Ultrasonic properties are very sensitive to composition and state of raw milk and other liquid food products. The first applications of ultrasound for food quality control started about 50 years ago for determining fat in milk and dairy products. Now the list of applications for optimization of quality and yield of food products comprises hundreds of items. The general principles of measurement of ultrasonic properties of liquids by standing waves are presented on Figure 1.

Sound velocity: $U = \frac{\Delta U}{Fn} . f$

Sound absorption: $\alpha = \frac{\delta fn}{f}$

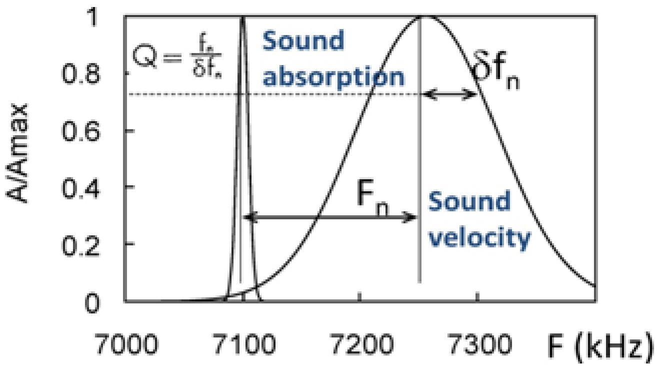


Figure 1: The resonance characteristics of control (*left curve*) and sample (*right curve*) ultrasonic standing wave resonator.

Multiple informative ultrasonic parameters can be measured: sound velocity and its temperature dependence, acoustic impedance, scattering, absorption, and its frequency dependence. The unique simplicity of the cylindrical-wave-based devices derives from the construction of the ultrasonic measuring chamber. This is just a tube, typically 10 mm long, excited at natural frequencies of radial oscillations of the liquid column filling the PZT piezoceramic tube [1, 2]. Devices based on the standing cylindrical waves will be far superior to other ultrasonic measurement instrumentation in respect to industrial requirements such as cost, precision, ease of use in flow-through systems, and measurement of very small samples of a few microliters. An analyzer sampling only a drop of the fluid provides an immediate and accurate result.

A single radially-polarized open piezotube resonator is very effective for simple dip-in monitoring of one or two acoustic parameters; for example, sound velocity and absorption. A differential version of an ultrasonic fat analyzer has one of the resonators filled with water and a second with milk or other dairy product (Figure 2). The main problem with the open piezotube is the difficulty of maintaining a constant temperature due to its low thermal conductivity.

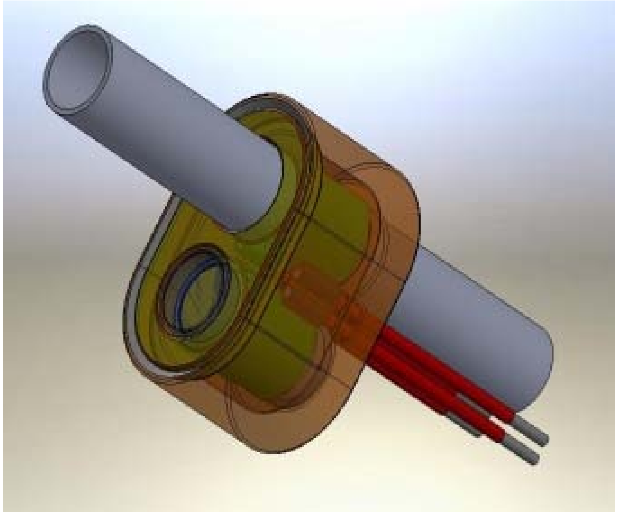
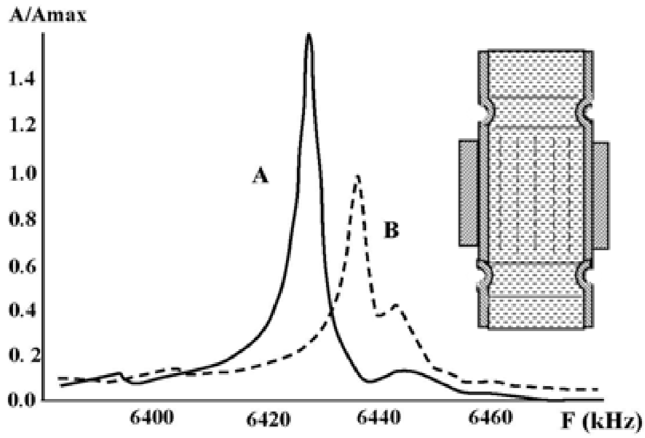


Figure 2: The cylindrical measurement chamber of the open piezotube, optimal for on-line monitoring and for easy cleaning.

Most industrial applications need high thermal stability of the sample during its analysis. The composite piezotube, where a metal or glass tube is covered by two or more segments of cylindrical piezoceramics (Figure 3), has a high thermal stability. Such resonators have been used in a multi-parametric milk analyzer, where a thermostability of 0.003°C is obtained. A temperature slope of ultrasonic properties of milk from 20 to 30°C enables specifically determining fat, protein, lactose, and SNF in milk. Metal tubes of the resonators can be used as electrodes for conductivity measurements at various frequencies [3]. The composite resonator includes non-interference bands formed by constrictions for isolating the area of the standing wave oscillations. Without such constrictions, waves traveling along the long axis would interfere with the standing waves within the resonator cavity and interfere with the clean separation of the large particles [4].



In **Figure 3** the resonance characteristics of the piezotube with (A) and without (B) constrictions on the resonator are compared. By limiting the ratio of length to radius of the tube of the resonator, one can significantly improve the quality factor and obtain high-resolution ultrasonic measurements.

The improved quality factor of the composite piezotube allows one to reach a higher intensity and to achieve a new feature of the cylindrical standing wave resonator: ability to concentrate and separate large particles (cells, fat globules) of the sample by the acoustic radiation forces. The cylindrical standing waves of high intensity create an acoustic radiation force that forms two areas of pressure, the node and the anti-node, where the fat globules can be trapped and determined (Figure 4). It is important to mention that the process of concentrating of particles in the piezotube is 200 times more efficient than in the plane standing wave resonator.

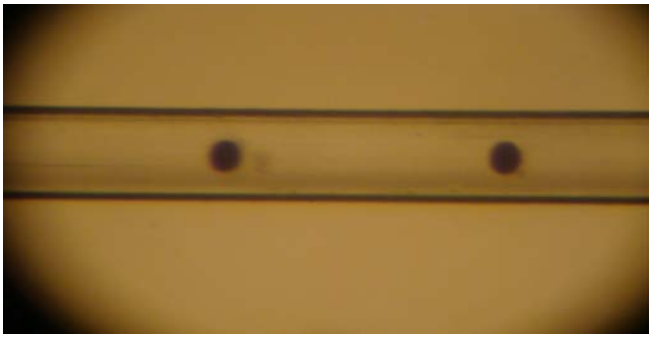


Figure 4: Represents the separation of fat globules in the milk by cylindrical standing waves.

3. Monitoring of the Milk Quality

A unique proprietary feature of the developed ultrasonic milk analyzer is that it employs a combined mode of operation using both high-intensity waves for separation and concentration of the micron-size particles (fat globules or cells) and low-intensity waves for compositional analysis. High accuracy for sound velocity measurements and sound absorption and rapid testing time (about 10 s) have been achieved (Figure 5).

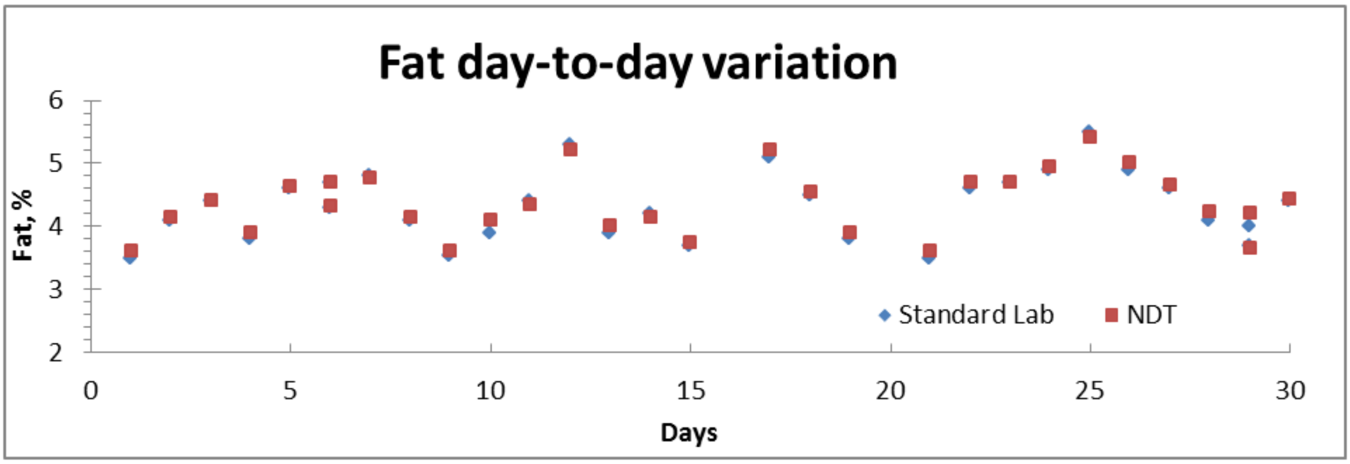


Figure 5: Comparative analyses of the ultrasonic method with standard reference techniques have produced linear calibration curves for major components with correlation coefficients higher than 0.95.

The technology can be incorporated in either a hand-held portable device or an add-on line component in existing flow-through systems. This will enable continuous on-line monitoring of the quality of milk, and will facilitate the prediction of mastitis and will determine the following main components: Fat (accuracy (±0.04%), Protein (±0.04%), Lactose (±0.05%), Somatic Cells (±30%). Alpha-prototype device design and construction are in progress and scheduled for March 2015.

In addition, it is possible to monitor salinity, turbidity, specific gravity, and particles (somatic cells) in raw milk directly. The final version of the device will be able to measure the following parameters of milk (Table 1):

Table 1: Ultrasonic characteristics of milk and dairy products

Ultrasonic Parameters	Properties of Milk Sample	Range
Sound velocity, U	Specific gravity (SNF)	0.90 to 1.20 g/cm^3
Acoustic impedance, ρU	Salinity (SNF)	0 to 100 ppt
Sound absorption, α	Viscosity (protein&fat)	1-100 cps
Dispersion of absorption, dα/dF	Vesicles and cells	0 to 200 mg/mL
Temperature slope dU/dT, dα/dT	Hydrophobic components (fat)	0 to 200 mg/mL

Preliminary testing of the analyzer was carried out on milk samples from five cows milked twice a day for one month. More than 300 samples of the raw milk were tested. Obtained results demonstrate the possibility of rapid measurements (10s) and good correlation with the central certified laboratory for milk quality testing run by the Cattle Breeding Association. Continuous monitoring of milk fat, protein, SNF, which typically have high day-to-day variation, provide a much-needed tool for dairy management and for veterinary diagnostic purposes. It was found that milk production level, stage of lactation, and outside temperature have significant influences on milk composition.

The key advantages of the ultrasonic analyzer using cylindrical waves are:

1. It measures protein, fat, SNF, as well as physical properties (conductivity, density, etc), and detects water and fat frauds in milk.
2. The results of analysis are immediate and on-line. There is no need for an intermediary laboratory and further delays, vital when considering a product with a short shelf life.
3. The analysis is executed per cow, eliminating the possibility of adding milk from an infected cow into a collection container.
4. Infected cows can be identified earlier and their milk supply stopped.
5. It can also be used on buffalo milk.

Table 2: indicates ultrasonic standing wave's technical advantages over leading existing competitors

Company	Parameter		
	Sound Velocity, U, %	Sound Absorption, α, %	Temperature, T, °C
NDT Instruments (Israel) Milk Analyzer UCC-12-2	0.0001	0.1	0.003
Biomer (Russia) Milk Analyzer KLEVER-2M www.biomer.ru	0.001	0.5	0.02
Milkotronics (Bulgaria) Lactoscan MCC/ LA / SA http://www.milkotronic.com	0.001	0.5	0.02

There will be two main instruments for the dairy sector:

- A manual unit for farming operations or to serve as a partial solution for small dairy farms that will not acquire the fully automatic system, or for use as a back-up to the automatic system.
- An automatic unit to be installed at each computerized milking station or for each suction cup. These units will be linked online to a PC or to a management system. The unit will stop milking a cow whose parameters are out of the decided range, thus preventing collecting-tank contamination.
- The field test of the milk analyzer will be done jointly with the Indian corporation Shree Kamdhenu Electronics Pvt., "AKASHGANGA", Gujarat.

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