Online Evaluation of Dairy Products

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Introduction

Milk is considered as a near balanced food and forms an integral part of our diet since time immemorial. Due to presence of high quality nutrients, it forms a suitable base for the growth of the pathogenic and spoilage microorganisms. It leads to the major economic losses as well as health problems to the consumers. Thus milk and milk products should be of high quality and properly delivered to the consumers in the safest condition by taking all necessary precautions during production, processing as well as marketing. One of the major points to control quality and safety is the processing site in the production unit. Hygiene at production unit is a very important aspect of milk and milk products safety. Thus, it is mandatory for dairy industry to guarantee the safety of the products.

The manual inspection of dairy products is very arduous and time consuming. In modern dairy industry, it is not possible to measure the quality of each and every products manually within no time due to the large volume of the production. This can be achieved by thoroughly examining the quality of each batch of the final products in as short duration as possible. Nevertheless the main disadvantage during this process is the finding of the deviation after the completion of process. This can be overcome by using HACCP principles in dairy. This process analyse the each steps in the processing starting from raw material to the final products, and any deviation during the process is identified and corrected at once. This approach minimizes the safety margins and significantly improves the profitability and productivity of the dairy processing unit. Finally it facilitates the control of the quality and safety of milk and products at the processing itself. This reduces markedly the time gap between the production and release of the products in the market by end testing of it in an analytical laboratory and increasing the efficiency and profitability. As we know for better quality and safety, the time gap between productions to end consumers should be minimum in case of milk and milk products.

To achieve the above mentioned goal, the whole process of quality measurement must be completed very fast to enable it by sampling and analysing the product in real time in the process stream segment or within a short time after the passing of the measuring point. This is known as "On-line measurement of the quality". It is called as "In-line" if the measuring point is in the processing line for better control of whole process and the term "at line" is used in case of measuring the quality of the products at in the production area. The sensors are basically the soul of any on-line inspection system. The sensors technology is giving a very good response at a relatively low frequency which is very important for the development of a low-cost sensing system.

The online measurement of products quality is the need of an hour for the production on large scale in the continuous process of the production in dairy. The inspection of products is completed in the processing line itself makes the measurement time nearly nil. The saving on the labour, less wastage due to inferior quality of the product, early reaching of the products into the market reduce the cost of storage and zeroing the chances of human error are also observed in the on-line measurement than the traditional offline measurement. It spotted out any wrong thing during the preparation of the products and thus facilitates the prompt corrective action. As the inspection and measurement is done very fast, so the accuracy remains the major concern in on-line analysis. The controllability is poor in on-line analysis as compared to off-line analysis.

Dairy processes are very fast processes and completed within a very definite time of hours, minutes or even seconds. The process control should have fast measurement in these continuous and automated processing and the less stringent demand on accuracy. The on-line inspects each and every item continuously and thus eliminates the need of batch sampling and minimise the sampling error. The analytical tools are placed at suitable sites for the proper measurement of the process.

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The following technology is used to measure the quality of dairy products:

1. Infrared Sensors
2. Imaging Techniques
3. Dielectric sensors
4. Process viscometer

1. INFRARED SENSORS

These are most prevalent sensors used for the evaluation of the quality, composition, sensory and rheological properties of milk products. The large size and higher cost of the infrared spectroscopy is the major curb in the utilization of this technology at small scale and at individual farm operations. Based on the spectrum of use, there are the following two types of infrared sensors widely used in dairy industry viz. near infrared spectroscopy and mid-infrared spectroscopy.

(A) Near Infrared Spectroscopy (NIRS)

It is a non-invasive technology, used for determination of composition of a variety of dairy foods such as milk (Carl, 1991; Kawamura et al., 2007), cheese (Frank and Birth, 1982; Molt and Kohn, 1993; Blazquez et al., 2004) and butter (Meagher et al., 2007) as well as the quality and authencity of milk, butter and cheese. NIRS refers to the range within the electromagnetic spectrum with wavelengths from approximately 760 nm to 2500 nm, slightly longer than visible light (approximately 400-760 nm). In combination with mid-infrared (approximately 2500-30000 nm), the sample is illuminated with a broad-band visible NIRS illuminant (usually extending down into the visible range) and the resulting (reflected/transmitted/transflected) NIRS light is detected and separated into its constituent frequency components over the NIRS range of the spectrum. The spectra measured are the result of intra-molecular vibrations due primarily to the covalent bonds within molecules. The discriminative power of NIRS lies in the very high signal-to-noise ratio, which enables subtle differences between signals, invisible to the naked eye, to be reliably used to discriminate between samples. NIRS requires relatively little quantity of sample and even its processing is very fast. The test may take only a matter of seconds per sample.

The sensory properties and age of cheddar cheese (Downey et al., 2005) and processed cheese have been judged successfully by NIRS. Kliman and Pallansch (1965) used infrared spectroscopy in the determination of the composition of butter oil and reported that 1900 nm as relative absorption of water in butter oil. The adulteration of upto 3% foreign fat in butter can be detected by using near-infrared spectroscopy. It is also found useful in the determining the composition of butter. The composition, quality and adulterations in milk powder are detected by NIRS. Reh et al. (2004) established that the absorbance at 1940 nm is highly correlated with the content of moisture in milk powder. Upto 0-5% vegetable protein adulteration in milk powder can be detected by using it. The quality of milk powder is dependent on the extent of heat treatment to the milk during the process. The milk powder can be differentiated into the different types of heat treatment by applying the NIRS.

The NIRS equipment should be placed closer to the process line. The majority of NIRS instruments is designed as laboratory instruments and is not particularly suited to on-line implementation, owing to issues around sample size, presentation, scan time, sample preparation and the delicate nature of the fundamental mechanisms. However, on-line instrumentation and applications are becoming more prevalent. NDC Infrared Engineering (Irwindale, CA, USA) currently markets the MM55plus, an NIRS food sensor for a variety of on-line food analysis applications.

The optical properties of coagulated milk are different than the normal milk due to the difference in the reflection of light from normal and coagulated milk. The reflection of light is increased and the transmission of light is decreased by the gel formation of protein due to the coagulation proteins in milk.

(B) Mid- Infrared Spectroscopy

Mild-infrared spectroscopy also known as “Fourier transform infrared spectroscopy” (FTIR) is a non-invasive technique of measurement of the products quality composition and authenticity of dairy products in a very short time by using the absorption radiation of 4000-400 per cm region of electromagnetic spectrum. At present this technique is mainly utilized in the rapid characterization of cheese and milk (Downey, 1998; Chen et al., 1998). Previously these equipments were very large and find difficulty in placing them in the processing line. With the introduction of guided wave optics and linear detector technology, the need of using a broad spectrum of the radiation is replaced by the narrow spectrum. This makes the development of miniature equipment suitable for the on-line and in-line measurement of the dairy products in the process line (Kruzelecky and Ghosh, 2002). Due to the better and faster results in compliance to the AOAC and IDF standards, are obtained by the mid-infrared spectroscopy. This technique is applying on commercial scale by designing the equipments such as Milkoscan FT 120.

The cheese industry is the one of the fastest growing industry in the world. The quality of a cheese is generally influenced by the moisture content, protein and fat content of cheese, the processing conditions, development of flavour, the starter culture, the texture and meltability of cheese. Thus to get a comparative price of cheese, it is necessary to control the composition as well as processing conditions of the cheese in the process line itself. The miniature mid-infrared spectroscopy equipments are used in the cheese production plants for determining the composition and textural properties. The springiness in cheddar cheese during ripening stage is well indicated by the characteristic bands in mid-infrared spectra (Irudayaraj et al., 1999). Regarding the identification of microbes in cheese, the Lactococcus spp. can be identified by the mid-infrared spectroscopy during ripening of cheese (Lefier et al., 2000). During cheese ripening, protein breaks down into smaller peptides by the proteolysis. The content of water soluble nitrogen (WSN) also increases with the advancement of ripening age of cheese. The ripening age of the cheddar cheese and emmental cheese can also be fairly judged by the use of this technology by measuring the WSN (Dufour et al., 2000). The FTIR is now a days increasingly be used in the assessing the sensory and physical parameters of cheese. At present, most of the dairy processing units in New Zealand measure the fat-to-protein ratio of milk using midinfrared spectroscopy prior to processing to provide an efficient and accurate method for determining the standardization of milk.

2. IMAGING TECHNIQUES

Humans basically use their sense of sight for the inspection of food materials. There are several efforts had been made to mimic this concept to judge the quality and composition of dairy foods in the process line in a very short time. This became possible by using of controlled illumination and by a camera configuration. With the introduction of camera with high resolution and power, monochrome light and colour or visible infrared light, the efficiency of this technology is further enhanced. It detect and discriminate between acceptable and unacceptable (including contaminants) product at high throughput rates. In dairy, the imaging techniques are used in assessing the sensory and physicochemical parameters based on the information collected on the surface and internal properties of the products.

The imaging technology comprises the various imaging technologies like computer vision, hyperspectral imaging (HIS), ultrasound imaging and nuclear magnetic resonance imaging (NMRI).

2.1 Computer Vision

This includes the process of acquiring, processing, analysing and understanding the images by mimic the human sense of sight by electronically understanding the image. This is possible by disentangling of symbolic information from image data using models constructed with the aid of geometry, physics, statistics and learning theory. This facilitates the automation and integration of a wide range of processes in dairy industry. The computer vision comprises of a source of illumination, digital camera for taking images, frame grabber or digitizer and computer with software. In dairy technology, the computer vision is most commonly used in assessing the textural properties of cheese with special emphasis on its melting properties. The cheese starts melting upon heating it and it causes an increase in the area of cheese. Meltability, an important functional properties of cheese to make it suitable for use as toppings or a basic ingredient in the food, is mostly dependent on the moisture content in cheese. The meltability of cheese is measured by computer vision after heating at various temperatures and then automatic analysing the effect of the heat on the melting properties of cheese. The meltability is previously assessed by taking into account the percent increase in the diameter and percent decrease in height of cheese upon heating. The cooking conditions and the meltability are not proportionately interrelated. The scorching of cheese disc at the outer edges as well as non circular cheese disc make it further difficulty to assess the meltability by simply heating it. Thus it is better to take into account the change in the whole spread area than the diameter of cheese disc during heating (Muthukumarappan et al., 1999).

The quality of cheese is determined during the processing stage by using computer vision. The images have been taken of the curd or whey in cheese vat during syneresis and put for analysis. The change in the area of whey to the curd and average RGB value provide a fair account to predict moisture content in cheese (Everard et al., 2007). A new reliable sensor system based on visible-NIRS and RGB imaging to assess the coagulation and syneresis and critical stages in the formation of cheese curd. These sensors improved the consistency and efficiency of the dairy processing. It is suitable for on-line evaluation of syneresis, provide continuous feedbacks by determining the threshold levels as well as improving the dairy economics by reducing the rejected or degraded volume.

Colour is an important factor that determines the first impression about the food products. In the modern dairy processing units, it is necessary to reduce the variation in the colours of the products. This can be achieved by a faster and reliable method of colour measurements such as computer vision. By computer vision the browning and meltability are assessed simultaneously in a very short time with greater precision. As unlike in the traditional colorimetric methods, this method covers the entire sample area into considerations without coming in the direct contact with the dairy products. This non-invasive nature of colorometry facilitates the assessment of colour of the products at higher temperature in a very short time (Wang and Sun, 2001). In the traditional methods of analysing the machined especially shredded cheese is done by sieving by focussing mainly on the fragmented pieces without taking into consideration the functionality of unbroken ends. By computer vision, we can also determine the length of single, touching and overlapping cheese shreds. The computer vision has given promising results in the colour evaluation of kunda, a heat desiccated dairy product.

Recently, there is an increasing awareness among the consumers towards the functional foods with added dietary fibre sources. In cheese industry, certain vegetables are added to make provide the dietary fibres as well as to reduce the cost of production. However, in cheese, these vegetables should be in a proper amount and equally distributed for better acceptability by the consumers. The amount and distribution of vegetables can be readily detected with higher efficiency by using computer vision as a sensor technology for the inspection of cheese.

2.2 Hyperspectral Imaging (HSI)

In this, the collection and processing of image is done across the electromagnetic spectrum. This divides the image into several electromagnetic spectral bands including that beyond the visible spectrum. These images are combined to form a three-dimensional spectrum which is further processed and analyzed. Some materials are having the unique pattern of bands commonly called as fingerprints of that specific material in the electromagnetic spectrum. These fingerprints act as spectral signatures for the identification of the materials. Thus this technology combined the beneficial aspects of conventional spatial image by computer vision and spectral image by spectroscopy (Gowen et al., 2007). It is a highly sensitive and can detect even minor constituents as well as defects in foods products. The handling of HSI is comparatively easy and simple but costlier. There is no need to have any prior knowledge due to taking into consideration of whole spectrum into each point.

There are numerous workers are working to know the suitability of this HSI technology in determining the quality and composition of dairy products. The optical properties of turbid liquids including milk are far better determined by HSI (Qin and Lu, 2007). The scattering effects or optical properties of milk are correlated with the fat content in milk. By analyzing the spatial images, the distribution of food constituents are easily detected by HSI. The amount of protein, fat and carbohydrate can be determined by using various image data and analyzing these data in the perspective of partial least square regression errors. The products with inhomogeneous distribution of the constituents can be assessed by changed colouration of spatial images. This has found its uses in cheese industry by making spatial images for determination of the pattern of fat distribution in cheese.

2.3 Ultrasound Imaging

Ultrasound imaging is also called as ultrasound scanning or sonography. It is also a non-invasive technology without using the ionizing radiation, widely used in medical science. It forms the real images by exposing the objects to ultrasound waves. The ultrasound imaging or sonography equipment consists of a computer, an electronics, video display screen and a small hand-held for scanning with microphone known as transducer. The ultrasound image becomes visible on computer screen. The image is created based on the amplitude (strength), frequency and time it takes for the sound signal to return from the area of the objects being examined to the transducer. Based on the acoustic properties of the objects, some of the waves are reflected while remaining is transmitted with different speed and extent depending upon the impedance through the object. These properties are useful to assess the different objects as well as difference within the same objects. Thus the sonography or ultrasound scanning is useful in detecting the extraneous materials in the objects as well as quality of the dairy products in a very short time.

Ultrasound imaging without making the direct contact with the dairy products especially cheese can detect the addition of any foreign materials during processing (Cho and Irudayaraj, 2003). This noncontact sonography is thus very useful in liquid materials due to reducing the chances of contamination by the transducers. The main problem faced in noncontact ultrasound imaging is the modification or alteration in the signals by the humidity and temperature of air. This problem is overcomed by using air instability compensation transducer with a fixed metal reference in front of its surface. The sonography can be utilized in mapping internal structure of cheese. This technology is successfully used in detecting artificial holes in cheddar cheese blocks. In Swiss cheese, ultrasound imaging is utilized in assessing the structure and pattern of eyes which in tern improves its quality and commercial value (Rosenberg et al., 1992). The formation of cracks, eyes, cheese matrix and ripening age of Swiss cheese are better assessed by the three dimensional (3D) ultrasound images.

2.4 Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI) is also known as "nuclear magnetic resonance imaging" (NMRI) or "magnetic resonance tomography" (MRT) is widely used in visualizing the internal structure, phase separation, component distribution, rheology and basic structure and composition of dairy food. There is an interaction between an external magnetic field and atom particles and electrons and nuclei during the MRI. It forms image of rotating nuclei of atoms under magnetic field without using ionization radiation. It is possible to produce two dimensional (2D) as well as three dimensional (3D) images with proper regulating the direction of nuclei.

In cheese industry, the application of MRI is rapidly increasing day by day. The pattern and the quality of eyes formed in Swiss cheese can be easily detected by applying MRI (Rosenberg et al., 1992). This is used to identify the low grade or defective cheese in the early stage of ripening during the processing and helps in making necessary corrective measures to solve the problem. Duce et al. (1995) used three NRM imaging methods viz. two-dimensional spin warp, three-dimensional missing pulse steady-state free precession and two dimensional Dixon chemical shift resolved imaging sequences for determining the quality of cheese. The two dimensional imaging is helpful in identification of holes, cracks or seams of moulds in cheese whereas three dimensional imaging helps to determine the shape and distribution of voids in cheese. The two dimensional Dixon chemical shift resolved imaging sequence found its use in separation of cream from milk over a 9 h period by mapping separately the spatial distribution of the liquid-like lipids and water in the milk. During spin wrap imaging air does not causes any NRM activity, thus appearing black in NRM imaging. The three dimensional images provide better clarity of shape and size of cheese. The 3D NRM micro-imaging has been used in evaluation of cheese curd grain structure. In commercial production and chilling of cheese, NRM is used to evaluate the pattern of distribution of moisture content in cheese, which ultimately affects the flavour and quality of cheese. This technology is useful in assessing the fat and moisture content in cheddar cheese. The rheological properties of yoghurt can be assessed by NRM which helps in making the suitable modifications in the design of the yoghurt making equipments for better control in processing.

3. <u>DIELECTRIC SENSOR</u>

Dielectric spectroscopy is a low cost sensing quality system for monitoring dairy products. Dielectric sensors also known as "capacitance sensors" use capacitance to measure the dielectric permittivity of a surrounding medium. The dielectric spectroscopy is a real time, very rapid and non-invasive technology for measuring the moisture and salt content of the food products. The dielectric sensors are safe, economical as well efficient and replacing the labour intensive and costly laboratory equipments. These sensors are widely used in the controlling of moisture and salt content of cheese and butter (Shiinoki et al., 1998). The better regulation of moisture and salt in butter and cheese is very important in continuous preparation for controlling the quality of the product. These electromagnetic sensors are increasingly utilized in the quality determination of dairy products such as milk, butter, cheese, curd and yoghurt. The dipole rotation occurs with ionic conduction during application of dielectric spectroscopy.

The dielectric properties of milk and its constituents like fat, protein and lactose have been determined by dielectric sensor at 2450 MHz. The composition of cheese has been determined by dielectric measurement at 750 MHz to 12.4 GHz (Green, 1997). Keam Holdem Associates have been developed an on-line dielectric sensor for determination of salt and moisture in cheese. The on-line dielectric sensors are very compact and robust consisting of a broadband antenna which directs the signal into the cheese block. These are fitted inside the butter pipe and take measurement by a sensor. These online sensors are capable of simultaneous determination of salt and moisture content. The processed cheese can be evaluated by the dielectric spectroscopy. The dielectric properties of processed cheese are varies with the heating temperature. The dielectric constant of processed cheese increase with the increase in the heating temperature from 55-75 °C and after 75 °C it decrease with the increase in temperature. The online measurement of salt and moisture in butter is very important for maintaining the quality and sensory attributes of the butter. However, the online measurement of the salt and moisture is very tedious and difficult but dielectric sensing is useful in this area (Shiinoki et al., 1998). They predicted the salt content in butter independently as salt content has greater has more effect on attenuation of the microwaves transmitted through salted butter than on the phase shift.

4. Process Viscometer

Viscosity is the resistance felt by a liquid during flowing and considered as important quality parameters of several dairy products. The viscosity is correlated with the consistency of food and thus directly influences the preference of consumer. It measures the viscosity of dairy products online or during processing line and thus helps in the production of good quality milk products as well as initiation of corrective measures to fix the problem during the processing line itself. Process viscometer forms an integral component in several dairy processing units such as milk powder production, condensed milk production etc. On-line measurement of viscosity provides a real time analysis of the quality of food.

Viscosity is a very important criteria to determine the quality of milk powder. During the production of spray dried powder, the viscosity of concentrated milk before atomization is very important to get the desirable characteristics and quality of spray dried milk powder. However, the viscosity of concentrated milk is affected by the non-Newtonian flow properties, age thickening characteristics and the presence of suspended solids and gas in it. This needed to make necessary modifications in the viscometer for on-line application. The selection of a suitable online viscometer should have conformity with grade standards, proper installation mode, compatibility to the output signals and operating conditions, a proper control parameter and should have compatible to the rheological properties of fluid. There is possibility of increasing the concentration of milk in evaporators without compromising the desired viscometry by proper application of on-line process viscometer (O'Callaghan and O'Donnell, 2001).

Conclusion

The online evaluation of dairy products in dairy industry has tremendous potential in guarantee the quality and safety of dairy products. Nowadays, the on-line evaluation of milk products composition and its quality have been successfully incorporated in the cheese, butter and milk powder industry. Continuous researches are goingon to make the on-line evaluation suitable for small scale and on-farm scale of production and processing of milk.

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