CHAPTER 2

DIGITAL IMAGE ANALYSIS: TOOL FOR FOOD QUALITY EVALUATION

PRASHANT G. WASNIK, REKHA RAVINDRA MENON, and BHUSHAN D. MESHRAM

CONTENTS

2.1 INTRODUCTION

Assurance and control of quality during and post processing is an integral part of the food processing industry. Conventionally, various subjective and objective methods are employed for the same. Subjective evaluation of quality stipulates the involvement of trained judges to visually identify, scale in linguistic terms or score in a numerical scale, the relevant quality parameters for the product. In addition to being a highly skill-oriented procedure, the subjective evaluation of quality is also time consuming, laborious and prone to human error and fatigue. Objective evaluation of quality is carried out using a range of measurement techniques, simple or sophisticated involving rigorous protocols of sampling and preparation steps of chemical analyzes and physical experiments. With the need for more rapid and economical objective measurement of quality, in recent times, computer vision technology or image analysis technique is garnering prominence as a relevant tool for the qualitative and quantitative assessment of quality parameters in food processing.

This chapter reviews image analysis as a tool for evaluation of food quality.

2.2 DIGITAL IMAGING

A digital image displayed on a computer screen is made up of pixels. These pixels are tiny picture elements arranged in matrix. The individual pixel can be seen by zooming up the image by magnifying tool. Width and height of the image are defined by the number of pixels in x and y direction. Each pixel has brightness or intensity value somewhere between black and white represented as a number. The intensity of the monochrome image is known as gray level. The limitations with regard to gray level are that it is positive and finite. The gray level interval varies from low intensity to high is called gray scale. A common practice is to represent this interval numerically as a value between 0 and L, where, the lowest value 0 represents pure black and the maximum value L is white. All intermediate values are shades of gray, varying continuously from black to white [23]. Digital image has a defined bit depth, such as 8-bit, 16-bit, or 32-bit, etc. When an 8-bit integer is used to store each pixel value, Grey levels range from 0 to 255 (i.e., $2^0–1$ to $2^8–1$).

2.2.1 READING THE IMAGE

In Figure 2.1, the name of the image is shown at the top of the image in title bar [87]. The image was scaled to 33.3% larger than the original and it

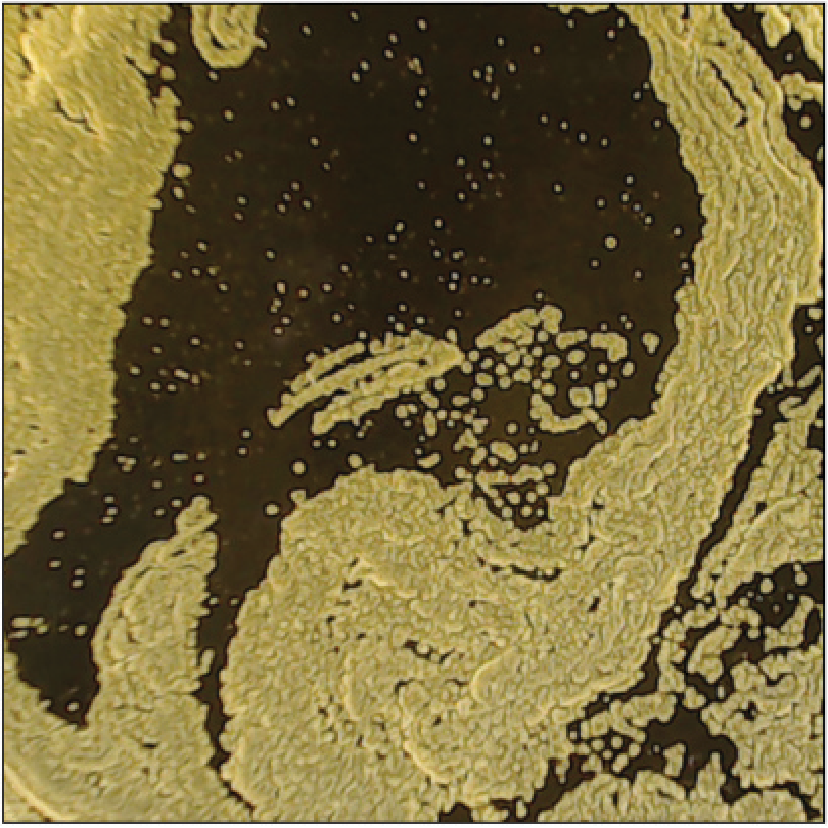

FIGURE 2.1 Digital image of cow ghee after crystallization at 28°C.

is saved in tagged image file (TIFF) format. The image properties are written below the title bar. The width and height of the image in mm and pixel is mentioned. The image is saved in 24 bit RGB (each color Red, Green and Blue) in 8-bit depth. The space occupied by the image is 8.3 MB.

2.2.2 IMAGE PROCESSING

We are familiar with the word food processing, where we are adding value to raw food material by applying various unit operations, in the same way in image processing we are adding value to image to extract meaningful information of our use from processed image by applying some mathematical operations on the raw image. In this process, we are not reducing the amount of data in the raw image but we are rearranging the data.

2.2.2.1 Purpose of Image Processing

The general objective of image processing for scientific and technical applications is to use radiation emitted by object. An imaging system collects the radiation to form an image. Then image-processing techniques are used to perform an area-extended measurement of the object features of interest. For scientific and technical applications area extended measurements constitute a significant advantage over point measurements, since also the spatial and not only the temporal structure of the signals can be acquired and analyzed [29].

The area of image analysis is in between image processing and computer vision. There is no clear-cut boundary in the continuum from image-processing at one end to computer vision at the other. However, one useful paradigm is to consider three types of computerized processes. Low-level processes involve primitive operations such as image pre-processing to reduce noise, contrast enhancement, and image sharpening. A low level process if characterized by the fact that both inputs and outputs are images.

Mid-level processing on images involves tasks such as segmentation (partitioning an image into regions or objects) descriptions of those objects reduce them to a form suitable for computer processing and classification (recognition) of individual objects. A mid-level process is characterized by the fact that both its inputs generally are images, but its outputs are attributes extracted from those images (e.g., edges, contours and the identity of individual objects). Finally higher level processing involves "making sense" of an ensemble of recognized objects, as in image analysis, and at the far end of continuum, performing the cognitive functions normally associated with visions [20].

Two types of errors are generally encountered while image processing: statistical and systematic errors. If one and the same measurement is repeated over and over again, the results will not be exactly same but rather scatter. The width of the scatter plot gives statistical error. The deviation of mean value of measured results from true value is called systematic error. In image analysis the statistical error may be large but the systematic error should be minimum [29].

2.3 DIGITAL IMAGE ACQUISITION

2.3.1 ILLUMINATION

Illumination is an important prerequisite of image acquisition for food quality evaluation. Acquisition of high quality image would naturally help to reduce the time and complexity of subsequent image processing steps, translating to a decreased cost of the image processing system and the quality of captured image is greatly affected by the lighting condition. By enhancing image contrast, a well-designed illumination system can improve the accuracy and lead to success of image analysis [23]. Also, the illumination strategy during image acquisition may depend on the intended application of the image processing technique. Most lighting arrangements can be grouped as front lighting, back lighting, and structured lighting [51]. The common lighting used in food research are: A (2856 K), C (6774 K), D65 (6500 K), and D (7500 K), etc. The illumination sources C, D65, and D are designed to mimic variations of daylight [36].

2.3.2 DIGITAL IMAGE ACQUISITION DEVICES

Image acquisition is capture of an image in digital form, and it is obviously the first step in any image processing system. During the last decades, considerable amount of research effort has been directed at developing techniques for image acquisition. A very intensive field of research in image acquisition is the development of sensors [14] and various configurations of sensors have been widely reported for the conversion of images into its digital form. In recent years, there have been attempts to develop non-destructive, non-invasive sensors for assessing composition and quality of food products. Different sensors such as charge coupled devices (CCD), ultrasound and magnetic resonance imaging (MRI), computed tomography (CT), and electrical tomography (ET) are been cited widely to obtain images of food products.

2.3.2.1 Scanner

In computing, an image scanner is a device that optically scans images (printed text, handwriting or an object) and converts it to a digital image which is then transferred to a computer. The scanner head (comprising of mirrors, lens, filter and Charge Coupled Device (CCD array) move over the document line by line by belt attached to steeper motor. Each line is broken down into "basic dots" which correspond to pixels. A captor analyzes the color of each pixel. The color of each pixel is broken down into three components (red, green, and blue). Each color component is measured and represented by a value. For 8-bit quantification, each component will have a value between 0 and 255 (2^8–1 = 255). The high-intensity light emitted is reflected by the document and converges towards a series of captors via a system of lenses and mirrors. The captors convert the light intensities received into electrical signals, which are in turn converted into digital data by an analog-digital converter. Scanners typically read red-green-blue color (RGB) data from the array. This data is then processed with some proprietary algorithm to correct for different exposure conditions, and sent to the computer via the device's input/output interface. Color depth varies depending on the scanning array characteristics, but is usually at least 24 bits. The other qualifying parameter for a scanner is its resolution, measured in pixels per inch (ppi), sometimes more accurately referred to as samples per inch (spi) [84].

The scanned result is a non-compressed RGB image, which can be transferred to a computer's memory. Once on the computer, the image can be processed with a raster graphics program (such as Photoshop or the GIMP) and saved on a storage device. During digital image processing each pixel can be represented in the computer memory or interface hardware (e.g., a graphics card) as binary values for the red, green and blue color components. When properly managed, these values are converted into intensities or voltages via gamma correction to correct the inherent non-linearity of some devices, such that the intended intensities are reproduced on the display [84]. Cross section of flat-bed scanner is shown in Figure 2.2 [11].

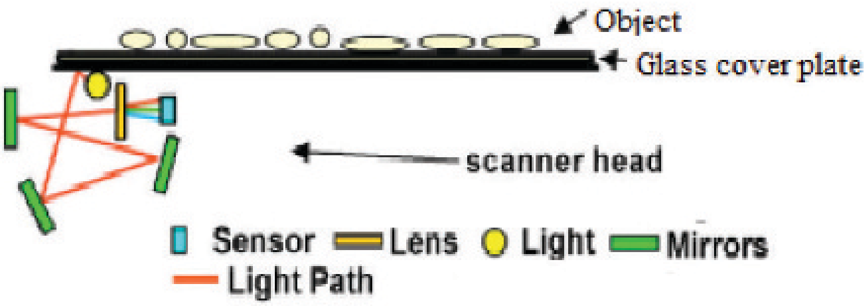

FIGURE 2.2 Cross section of a flatbed scanner used for scanning the food.

2.3.2.2 Digital Cameras

Digital cameras have a built-in computer, and all of them record images electronically. Firstly, light bouncing off an object passes into the camera, through a set of lenses, and onto a mirror. From there, the light bounces up and into a pentaprism. Once light enters the pentaprism, it bounces around in a complicated way until it passes through the eyepiece and enters our eye. Just like a conventional camera, it has a series of lenses that focus light to create an image of an object. But instead of focusing this light onto a piece of film, it focuses it onto a semiconductor device that records light electronically. A computer then breaks this electronic information down into digital data [10].

The fundamental technology of the digital camera is a light sensor and a program. The light sensor is most often a CCD and the program is firmware that is embedded right into the circuit board of the camera. The CCD is like a grid of millions of little squares, each one kind of like a solar cell. Each of those little squares on the CCD takes light energy and converts it to electrical energy. Each brightness and intensity condition of the light generates a very specific electrical charge. Those charges for each little square are then transported through an array of electronics to where it can be interpreted by the firmware. The firmware knows what each specific charge means and translates it to information that includes the color and other qualities of the light that the CCD picked up. This process is done for each of the squares in the grid of the CCD. The next step is for the firmware to record the information it saw into digital code. That code can be used to accurately reproduce the picture again and again. Now, that code can be passed to the view screen on the camera, or to a monitor or printer for reproduction [33]. Essentially, a digital image is just a long string of 1s and 0s that represent all the tiny colored dots – or pixels – that collectively make up the image. A digital camera with a minimum resolution of 1600 × 1200 pixels is recommended, which is equivalent to a 2.1 megapixels or higher camera for acquiring scientific images. The camera should also have macro and zoom feature. A memory card of at least 32 Mb and a digital film reader are also useful for storing the image files and transferring them to the computer [90].

A standard software can be employed /used to analyze a displayed image file created after digital scanning or photography both for color parameters and for the reflectance or luminosity. Modern color flatbed scanners, digital video cameras, and their image-processing software (graphics editors) provide wide possibilities for creating and editing images and their analysis [81, 82].

The colorimetric parameters of colored substances adsorbed on polyurethane foam can be measured using a desktop scanner and image-processing software [70]. In this method colored samples of polyurethane foam were scanned using a desktop scanner, the scanned color images were processed using Adobe Photoshop as a graphics editor, and the calibration plots of the luminosity of the selected channel (R, G, or B) as a function of the concentration of the test compound were found out using the Origin software. They prepared and scanned different colored chemical solutions. The separation of colors of images and the determination of the luminosity of R, G, and B channels were made using Adobe (R) Photoshop 8.0 software. The calibration plots were described by a first-order exponential decay function. It has been found that substances adsorbed on polyurethane foam can be determined with the use of a scanner and the corresponding image processing software with the same sensitivity as with the use of diffuse reflectance spectroscopy [76].

2.3.2.3 Digital Microscopy

Digital microscopy has been extensively used by many workers for characterization of food microstructure. Conventional optical microscope to obtain the images of bovine sodium caseinate (NaCAS) and soy protein isolate acid gels to access the possible changes in the microstructure can be used [27]. Polarization microscope equipped with a digital camera was used to acquire the hot stage images of starch/sodium chloride gels to study its microstructure [38]. The advantages of confocal scanning light microscopy (CSLM) over conventional microscopy that very thin focal plane can be observed by blocking the out-of-focus light through confocal optics [40]. They used a Bio-Rad 1024 CLSM system with Nikon Eclipse microscope for imaging the lipid microstructure. The images of low fat yogurt manufactured with microparticulated whey proteins acquired with confocal laser scanning microscopy used to investigate the difference in microstructure [83]. The images of concentrated milk suspensions and concentrated milk gels having similar casein composition acquired by transmission electron microscope equipped with CCD camera are also used to investigate the microstructure.

The basic tool for digital image processing consists of camera which acts as an electronic imagining system, having two main components lens and sensor. Lens collects radiation/refection to form image of the object features of interest and sensors converts irradiance at the image plane into an electric signal. Frame grabber converts electric signal into a digital image and stores it in the computer. Computer provides platform for digital processing of image and image processing software

1. **Input**
2. **Image acquisition**
3. **Pre processing**
4. **Feature extraction**
5. **Classification**
6. **Post processing**
7. **Decision**

FIGURE 2.3 The steps or components in the production of digital image.

provides algorithms to process and analyze contents of digital image [29]. A typical computer vision system can be divided into components (Figure 2.3). The components of machine vision system are described in following subsections.

2.3.3 IMAGE PRE-PROCESSING

Images captured by any image acquisition device are expected to experience various types of artifacts or noises. These artifacts may distort the quality of an image, which subsequently cannot provide correct information for successive image processing. In order to improve the quality of the image these artifacts needs to be removed by performing some operations on the image. The objective of the pre-processing operations is to improve and enhance the desired features for further specific applications. Generally two types of pre-processing operations are carried out for food quality evaluation: (a) pixel pre-processing; and (b) local pre-processing, according to the size of the pixel neighborhood that is used for the calculation of new pixel [14]. In pixel pre-processing method, input image is converted in such a way that each output pixel corresponds directly to the input pixel having the same coordinates. Pixel pre-processing may be viewed as a pixel-by-pixel copying operation, except that the values are modified according to specified transformation function. Color space transformation is the most common pixel pre-processing method for food quality evaluation [14].

Local pre-processing methods calculate the new value by averaging the brightness value of some neighborhood points, which have similar properties to the processed point [22]. Relatively simple and at the same time most complicated algorithms are available in ImageJ software to carry out this operation. Local pre-processing can be used to blur sharp edges, or to preserve edge in the image as per the demand of the specific problem. The median filter technique, a special group of filters called rank statistic filter, is observed to preserve the edges while filtering out the peak noise and is therefore the popular choice for filtering before applying an edge detection technique. For some special aims, more complex local preprocessing methods have been applied for food quality evaluation. The 'filter factor,', for example, modified unsharp filter transform, which is a Laplace transform of an image added to the same image, to enhance the detection cracks in the image of whole egg without overly enhancing other surface features and noise [22]. It is reported that this operation followed by a contrast stretch produced very satisfactory results as the sensitivity to translucent spots was decreased while sensitivity to cracks was increased. To smoothen a binary oyster image, shrink, expansion, and closing processes can be used. The shrink operation is applied to remove small objects (e.g., noise) in the image while the expansion process fills the holes and concavities in objects in the image [71].

2.3.4 IMAGE SEGMENTATION

Partitioning of an image into its constituent objects is known as Image segmentation which is a challenging task because of the richness of visual information in the image. The techniques of image segmentation developed for food quality evaluation can be divided into four different theoretical approaches, for example, thresholding-based, region-based, gradient-based, and classification-based segmentation. Current literature survey on image segmentation indicates that in most applications thresholding-based and region-based methods have been used for segmentation [14]. The other methods (gradient based and classification-based approaches) are used less frequently.

2.3.4.1 Thresholding-Based Segmentation

Thresholding-based segmentation is a particularly effective technique for images containing solid objects and having contrasting background, which distinguishes the object from the remaining part of an image with an optimal value. Among the thresholding-based segmentation methods for food quality evaluation, some perform segmentation directly by thresholding, and others combine the same with other techniques. Thresholding works well if the objects of interest have uniform interior gray level and rest upon a background of different, but uniform, gray level. For fast and computerized detection of bruises in magnetic resonance images of apples method is available in literature [93] in that computationally simple thresholding technique is used to distinguish between bright pixels representing the vascular system and those representing bruises. Whole pizza image is segmented from the white background using the RGB model and by setting the HSI values, segmentation of pizza sauce from pizza base can be achieved [76].

The defects of curved fruits can be segmented by generating the reference fruit image and it is normalized to get the normalized reference fruit image (NRFI) for inspection. The normalized original fruit image is subtracted from NFRI and a simple thresholding process is used to extract the defects [39]. It is recommended that the application of adaptive thresholding techniques instead of a fixed global threshold to segment an image for non–curvilinear fruits. Various automatic thresholding techniques are available in literature of which modified Otsu's algorithm can be used for successful automatic background segmentation of corn germplasm images [54].

2.3.4.2 Region-Based Segmentation

Region-based segmentation methods are divided into two basic classes: region growing-and-merging (GM) and region splitting-and-merging (SM) [91]. The former is a bottom-up method that groups pixels or subregions into larger regions according to a set of homogeneity criteria; and the latter is a top-down method that successively divides an image into smaller and smaller regions until certain criteria are satisfied. Region-based algorithms are computationally more expensive than the simpler techniques, for example, thresholding based segmentation, but region-based segmentation is able to utilize several image properties directly and simultaneously in determining the final boundary location. A region-based segmentation method, for example, the flooding algorithm, was developed to detect the apple surface feature [91].

Sun [76] developed a new region-based segmentation algorithm for processing the pizza images. This new algorithm adopted a scan line-based growing mode instead of the radial growing mode employed in traditional region growing algorithms. It uses the traditional region-based segmentation as a dominant method and combined the strengths of both thresholding and edge-based segmentation techniques.

2.3.4.3 Gradient-Based and Classification-Based Segmentation

Gradient-based approaches attempt to find the edges directly by their high gradient magnitudes and are similar to edge detection based on the gradient of an image. This image segmentation algorithm involving edge detection and boundary labeling and tracking is used to locate the position of whole fish [30]. However, the application of the gradient-based segmentation is limited because completed boundaries are difficult and sometimes impossible to trace in most food images. Classification-based methods attempt to assign each pixel to different objects based on classification techniques like statistical, fuzzy logic, and neural network methods. The Bayesian classification process can be used successfully to segment and detect apple defects [37].

2.3.5 PARTICLE ANALYSIS

Characterization of a population of granular objects is needed for many industrial processes, particularly in the food industry. According to its speed, accuracy and non-destructive operation abilities, image analysis is well-adapted tool for this purpose [52]. Quantitative analysis of morphological characteristics such as shape, size, count, area, perimeter, density, porosity, etc. can be estimated with particle analysis. Various software such as LUCIA, Image-pro, MATLAB, ImageJ, FIJI, etc., are available for particle analysis. Large number of workers worked on particle analysis protocol, selected work is briefly explained below for readers.

The microbial colonies in food matrices can be measured accurately by novel noise free method based on time-lapse shadow image analysis [52]. Flat bed scanner images of single layer rice kernel on a black background were used to measure length, width and area of rice kernels [11]. The distribution parameters, aspect ratio, density and number of broken kernels can be calculated from the measured results. The per cent area occupied by calcium lactate crystals on the surface of smoked cheddar cheese; size and shape distribution of fat particles in a model processed cheese product and the amount of surface area occupied by gas holes in cheeses using image analysis can be quantitatively analyzed [7, 61, 77].

The rapid particle size distribution analysis of Bacillus spore suspension can be measured with an image particle sizing analysis software and the dimensions such as length, breadth and perimeter of single spores can be determined [11]. For identifying shapes and determining particle size distribution, an Image-plug-in extracts the dimensions from digital image of disjoint particles [61].

The example of image processing steps involved in particle analysis of *ghee* (Clarified butter fat) particles is discussed below to understand the concept. The image acquired by web cam is calibrated in mm. Rectangular ROI of 24.52 × 24.52 mm (1476 × 1476 pixel) is selected and central portion of the image is cropped and converted to gray scale image by 8-bit ImageJ command. Cropped image in Figure 2.3 shows the typical region of interest. The brightness and contrast of the cropped image is adjusted by auto mode. The image is pre-processed by applying Gaussian Blur filter of Sigma 10. The blurred image is subtracted from original image and new image of 32 bit is obtained (shown as subtracted image). The resulted image again converted to 8 bit and the unsharp mask filter of radius 50 pixels and 0.9 mask weight was applied to remove the surface layer and sharpen the boundaries. Huang auto threshold protocol with upper and lower limits of gray scale intensities 228 and 255 is applied for image segmentation. The particle analysis is carried out with size range 0.01- infinity to avoid noise and very small particles with circularity 0.1 to 1 on the processed image. The transitions of images are shown in Figure 2.4 [87].

2.4 POROSITY

Porosity or void fraction is a measure of void spaces in a material and is a void fraction of volume of voids over total volume usually expressed as a per cent. This property is very important in case of baked products (such as bread, milk cake, *gulabjamun, rasogulla, pantua,* etc.), as it imparts

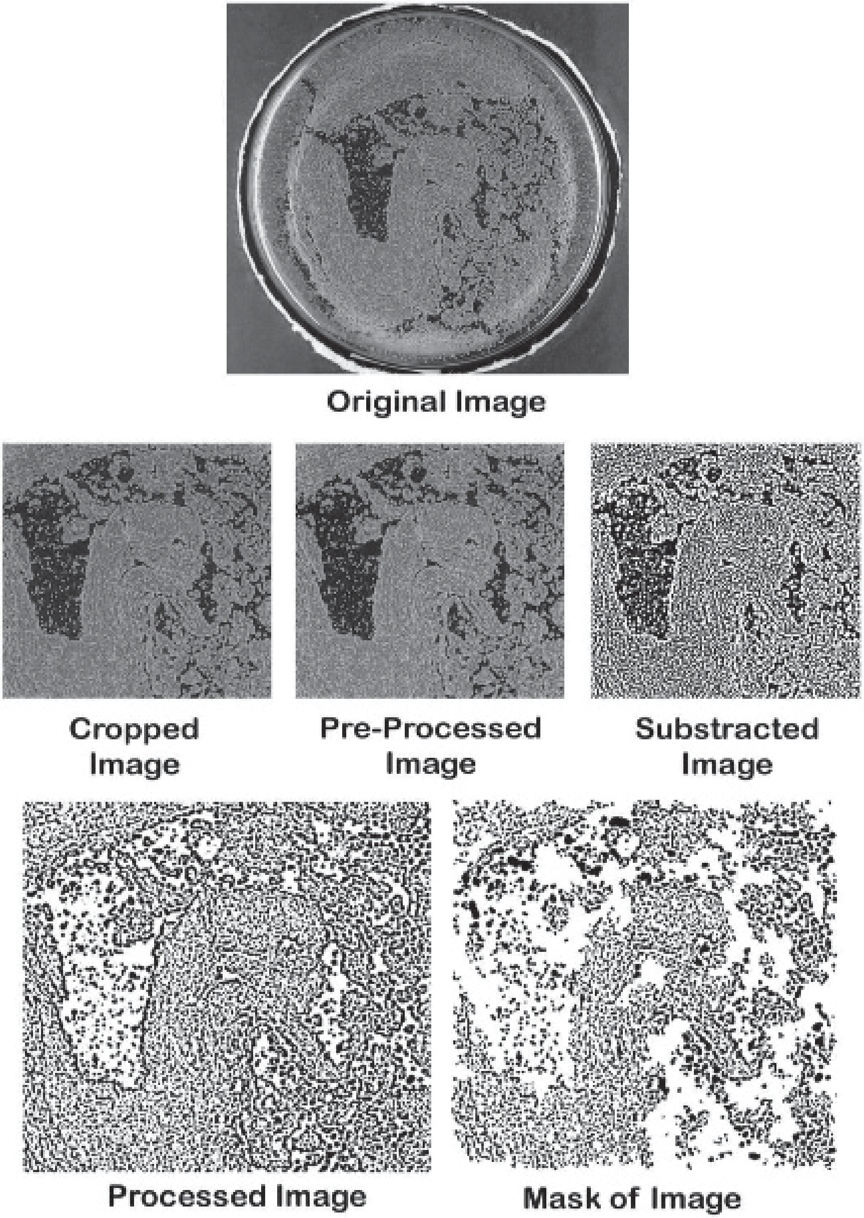

FIGURE 2.4 Image processing steps.

sponginess to the product. Various methods are available for measurement of porosity of food products but image analysis technique provides the easiest way to measure the same. To elaborate the technique the acquired and segmented image of milk cake is shown in Figure 2.5. The image of section of milk cake was acquired by flat bed scanner. The portion of void spaces can be seen in segmented image. With the help of ImageJ the total area of void spaces and per cent area of voids can be measured with particle analysis protocol.

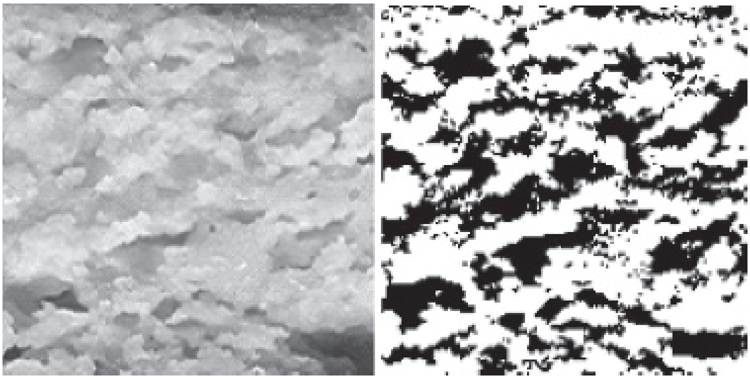

FIGURE 2.5 Acquired and segmented image of milk cake.

2.5 IMAGE TEXTURE ANALYSIS

Texture is an essential image attribute and has been applied greatly in the food industry for quality evaluation and inspection. A clear scientific definition, for image texture has not yet been available due to the limited understanding of texture properties as there is an infinite diversity of texture patterns of images [77]. The concept of texture in image processing/computer vision is totally different from the conventional concept of texture followed in the food industry. Currently in the food industry, food texture parameters, such as, hardness, cohesiveness, viscosity, elasticity, adhesiveness, brittleness, chewiness, and gumminess, is usually correlated to the manner in which human mouth perceives the mouth feel of the food while image texture descriptors, such as, fineness, coarseness, smoothness and graininess, are generally characterized by

IMAGE TEXTURE	Statistical texture	GLCM
		GL pixel run length matrix
		Neighboring GL dependence matrix
	Model based texture	Fractal model
		Auto regression model
	Transform based texture	Convolution mask
		Wavelets transform
		Fourier transform

FIGURE 2.6 The classification of image texture.

the spatial arrangement of the brightness values of the pixels in a region in the image [7].

There are four different types of image texture: statistical texture, structural texture, model-based texture, and transform- based texture [92]. Statistical approaches are employed to extract statistical textural features from the higher-order of pixel gray values of images while structural textural descriptors are acquired through certain structural primitives constructed from gray values of pixels. Transform-based texture is derived by using statistical measurements from transformed images. Model-based texture is obtained by calculating coefficients from a model based on the relationship of the gray values between a pixel and its neighboring pixels. Among these, statistical texture is the most widely reported during image analysis in the food industry due to its high accuracy and less computation time [92]. Transform-based texture and model-based texture are also used, although not as popular as statistical texture. However, structural texture is rarely used in the food industry. The selection of suitable method for image texture analysis has been restricted by the limited understanding of each of the methods suited for specific applications and the approach of employing different methods concurrently improved the final results [92]. The classification of image texture is depicted in Figure 2.6.

2.5.1 GREY LEVEL COOCCURANCE MATRIX

Grey Level Cooccurance Matrix (GLCM) is a statistical surface measuring algorithm, widely used for food texture evaluation. It can evaluate 14 different texture parameters in four different directions, by comparing the neighboring pixels. It tabulates how frequently different combinations of pixel brightness values occur in an image. At a time it considers the relation between two pixels, one considered as the reference and the other as neighbor pixel. Starting in the upper left corner and proceeding to the lower right of window each pixel within the window becomes the reference pixel in succession. Pixels along the right edge have no right hand neighbor, so they are not used for this count. Generally north, north east, east and south east directions are used to calculate GLCM texture attributes and then summing the counts. For evaluating the food texture one direction and one distance between the pixels is used. Angular second moment, contrast, correlation, inverse difference moment and entropy can

TABLE 2.1 Texture Parameters with Its Texture Features

Texture parameter	**Texture feature**
Angular second moment	Uniformity of an image
Contrast	Amount of local variations present in an image
Correlation	Pixel linear dependence
Entropy	Amount of the order in an image
Inverse difference moment	Homogeneity of an image
Sum of squares	Roughness of the image

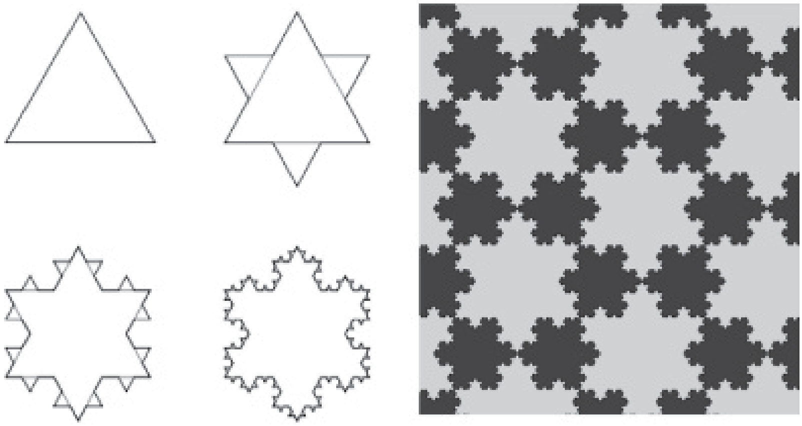

FIGURE 2.7 The von Koch snow flake.

be calculated from GLCM matrix and used as descriptors of food texture. The commonly used six features are listed in Table 2.1.

2.5.2 FRACTAL ANALYSIS

Fractal geometry is a relatively new branch of mathematics proposed by a mathematician called Benoit Mandelbrot who introduced a generically different concept of dimension to account for the complicated geometrical figures with finite and infinite boundary. Fractal (derived from the Latin word *fractus* meaning broken) is applied to define broken or problematic shapes illustrated for example by the von Koch snow flake (Figure 2.7) [69].

The basic definition of a fractal indicates that it is a geometrical object consisting of mostly broken lines constructed by an iterative process using infinite repetitions of a set of operations such that geometrically it appears as infinite multiples of self-similar units [69]. A classical example of this geometry is demonstrated in all related literature in the form of the snow flake boundary; zooming into the boundary results in infinite number of triangles, each side of which could be further zoomed to appear as a set of self-similar triangles. A self-similar fractal is often defined using Hausdorff dimension (named after the mathematician bearing the same name):

$$sd = c \quad (1)$$

where, *d* is the Hausdorff dimension, *c* is the amount of new copies one gets after one iteration, and *s* is the scaling factor.

The dimension for non-self-similar fractals are designated in other ways, one of the methods commonly cited is the box-counting method. This method involves the "covering" of the image or superimposing the image with smaller objects, usually circles or squares, or hyper cubes or balls in whatever topological dimension the fractal set fits in. The minimum number of objects required to completely cover the fractal is calculated to obtain the fractal dimension. This is referred to as the box-counting dimension of a fractal [69].

The dimension of line, a square and a cube are one, two and three, respectively and its distance, area and volume, respectively are easily measurable. However, we cannot measure the dimension of complicated self-similar or dissimilar objects such as fat crystal network. The fractal dimension is a unit that could help to measure the dimension of complex objects [45]. The degree of complexity of such objects is measured by evaluating how fast the measurements increase or decrease as the scale becomes larger or smaller. To calculate the box- counting dimension, a grid is placed on a digital image. The reciprocal of the width of grid is taken as 's' and the count of number of blocks that touches the digitalized image is taken as N(s). The process is repeated by resizing the grid and the fractal dimension is measured as the slope of best fit line of log N(s) versus log (1/s) plot [45, 60].

The fractality of fat crystal networks is calculated by particle counting procedure based on counting the number of particles within boxes of increasing size corresponded to the fractal dimension of the network and a grid type box counting method can be used to determine the fractal dimension [45].

Various methodologies can be used for calculating the fractal dimensions. For calculating, the Fractal features can be extracted by traditional threshold method using ImageJ freeware or by applying "High Pass filter" in Photoshop software. For semisolid foods such as retrograded starch or yogurt images obtained with confocal microscopy will be useful for studying the fractality with suitable image processing algorithm. Fractal analysis in combination with PCA is a robust and objective tool to detect and quantify morphological changes in the microstructure of stirred yogurt manufactured with micro-particulated whey protein as ingredient.

The fractal dimension is very useful for measuring the quality of habitats. Area and perimeter fractal dimensions can be correlated with ecological index for habitat quality. The interior to edge ratio is also suitable for predicting interior habitat quality [26].

Bulk density particle diameter relation, Richardson's plot, gas adsorption and pore size distribution methods can be used for estimating the fractal dimensions of fine food particles of native and modified starch.

The perimeter and surface area of particles can be used effectively to calculate the natural fractal dimensions of caseinate structures [15]. The fractal dimensions can be used to relate morphological features to functional or even sensory properties, thus assisting food product development, process control and quality assurance [5].

2.5.3 ANGLE OF REPOSE

When bulk granular material is poured on to a horizontal surface, a conical shape of piled granular material will form. The internal angle between the surface of pile and the horizontal surface is known as the angle of repose. It is related to the density, surface area, shapes of particles, coefficient of friction. Materials with a low angle of repose form flatter piles than materials with a high angle of repose. In ImageJ a dedicated angle tool is provided for measurement of angles. Simply by drawing line over the angle of acquired image of pile the angle can be measured.

2.5.4 IMAGE COLOR ANALYSIS

Color measurement is not straightforward because it varies with the amount or intensity of mixture of primary colors which form innumerable color shades. Consequently, no single color measuring system encompasses these numerous combinations, leading to variations in color expressions. The Commission International de l'Eclairage (International Commission on Illumination, CIE) has been involved in defining a standard system to effectively express color in all possible combinations since 1930 and the proposed systems have been progressively refined and upgraded. In 1976, CIE recommended the CIELAB color scale, which measures color using three coordinates, the L*, a* and b* [18]. L* is the luminance or lightness component, which ranges from 0 to 100, and parameters a* (from green to red) and b* (from blue to yellow) are the two chromatic components, which range from –120 to 120 [91]. The L*a*b* color space is recommended as an absolute model to be used as a reference as it is perceptually uniform and device independent [55].

The CIE Color Systems utilizes a three coordinate system to locate any color in a color space; the commonly employed co-ordinate systems include CIE XYZ, CIE L*a*b* and CIE L*C*h. An alternate color scale commonly employed was developed by Hunter in 1958 and is also expressed as three coordinates, namely, L, a, and b with almost similar definitions to the CIE L*a*b* scale parameters but computed differently [43]. Most modern colorimeters automatically calculate either the CIELAB values or the Hunter values.

Color of food products is reported to be measured by various methods namely: spectrophotometers, colorimeters, color charts and computer vision methods. All these methods use one or the other expressions of color measuring systems viz. CIE XYZ, Lab, L*a*b* or Munsell color scale. Out of these color measuring systems, CIE L*a*b* is the most accepted and commonly used system because of its wide spectrum involving maximum number of color shades. However, CMYK mode is commonly used in printing systems [64]. The various equipment and techniques used for color measurement are briefly discussed in the following subsections.

2.5.4.1 Spectrophotometer

Spectrophotometry has been cited for boundless applications including corporate logo standardization, color control in paint industry, color testing of inks, color control for packaging material and labels, color control in plastics and textiles industry and monitoring of food color throughout the development, manufacturing and storage process. The principle of spectrophotometry is based on the capture of reflected light of well-defined wavelength incident on the sample. The commonly reported spectrophotometers employed for monitoring color include Spherical spectrophotometers, 0°/45° spectrophotometers and Multi-angle spectrophotometers [63].

The spectrophotometer was used to monitor the color of evaporated milk and related products and a convenient index for routine estimations of the darkening in color of evaporated milk was determined by noting changes in reflectance of light of 520 μm wave length [49]. Near infrared (NIR) spectroscopy and Hunter-lab can be employed to predict color of European Emmental cheese samples [57]. The reflectance method was also used to measure milk fat color differences due to various parameters like feed of cattle [73].

2.5.4.2 Colorimeter

A colorimeter is a device of fairly simple design based upon the visual concepts of color [49]. The sample is illuminated with a single type of light (such as incandescent or pulsed xenon) at a 45° angle relative to the perpendicular line to the plane of the mounted sample. The reflected light is measured directly perpendicular to the sample through a series of three and sometimes four colored filters which represent the relative amounts of red, green and blue light reflected from the sample. More specifically these filters are designed to ideally simulate the three functions, x, y, z so that the instrument directly measures the three tristimulus values X, Y, Z for the specific illuminant being used [63]. The other essential parts of a tristimulus colorimeter are a white light source, an array of photometers and, nowadays, a computer or an interface to one. The computer is used to collect responses as well as carry out data transformations between CIE and other color scale systems or between different standard white light sources or white diffusers. Data from a colorimeter is given as a three-point output, commonly CIELAB, Hunter Lab or Y, x, y [34, 31]. The reflectance meter was used for color measurement of *basundi* and the color is expressed in terms of percent transparency (T) for brown and yellow color [13].

2.5.4.3 Stimuli Meter

Stimuli meters are based on the principle wherein color measurement is carried out by using a combination of stimuli to match given stimulus, for example, the color of solvent or material being measured is carried out by matching against a given system of known colors. Examples of these are Munsell Systems, the Donaldson instrument and Lovibond tintometers [28].

2.5.4.4 The Munsell Scale

In colorimetry, the Munsell color system is a color space that specifies colors based on three color dimensions: hue, value (lightness), and chroma (color purity or colorfulness). Munsell was the first to separate hue, value, and chroma into perceptually uniform and independent dimensions, and was the first to systematically illustrate the colors in three dimensional space [35]. There are 10 hues and each hue is subdivided into 10 shades. The value is evaluated on a scale that ranges from 0 at black to 10 at white. The chroma is expressed on an arbitrary scale of saturation ranging from 0 to 18. The Munsell system assigns numerical values to these three color dimensions. The color produced in the processing of evaporated milk is measured by means of the Munsell system of disc colorimetry [3, 88].

2.5.4.5 Color Charts

A dictionary consisting of 56 charts is classified into seven main groups of hues presented in order of their spectra. Each group, comprised of eight plates, the first plate was painted white with successively darkening shades of gray until the color appeared black. These colors were defined using CIE terms and are convertible to Munsell values [43]. The disadvantage of the color chart was its difficulty to match when the surface was different and possible deterioration of the painted paper-standard through exposure. A color chart for determination of the color of *basundi* was prepared using reflectance meter and had color combination of Red:Green:Blue as 205:150:0 [13].

2.5.5 COLOR MODELS

Three color models are commonly used to define color: RGB (red, green, and blue) model; the CMYK (cyan, magenta, yellow and black) model; and the L*a*b* model. While these color models have been established as useful quantifiers of color, it has also been pointed out that the spectrum of colors seen by the human eye is wider than the gamut (the range of colors that a color system can display or print) available in any color model [63].

2.5.5.1 RGB Model

RGB model is an additive color model that uses transmitted light to display colors in which red, green, and blue light are added together in various combinations of proportions and intensities to reproduce a broad array of colors. RGB is derived from the initials of the three additive primary colors, red (R), green (G) and blue (B). The model is said to relate closely to the way human perceives color on the retina. The model is device dependent, since its range of colors varies with the display device [58].

2.5.5.2 CMYK Model

CMYK refers to the four inks used in most color printing: cyan (C), magenta (M), yellow (Y), and key black (K). In contrast to the RGB model, CMYK is subtractive in nature. Since RGB and CMYK spaces are both device-dependent spaces, inter-conversion of the obtained color values using these models is neither simple nor mathematically established [2].

2.5.5.3 Lab Model

The L*a*b* color is a device independent model, providing consistent color regardless of the input or output device such as digital camera, scanner, monitor and printer [31]. Among the three models discussed herewith, the L*a*b* model has the largest gamut encompassing all colors in the RGB and CMYK gamut [2]. The L*a*b* values is the most widely reported color scale in food research studies. Unlike the RGB and CMYK color models, Lab color is designed to approximate human vision; it is attributed with an aspiration to perceptual uniformity, and its L component closely matches human perception of lightness. The model is also conducive to make accurate color balance corrections by modifying output curves in 'a' and 'b' components, or to adjust the lightness contrast using the L component [2].

The surface color of images acquired by imaging system can be measured using Adobe Photoshop in Lab mode. The L a b values thus obtained can be converted in terms of CIELAB L*, lightness ranging from zero (black) to 100 (white), a* ranging from +60 (red) to −60 (green) and b* ranging from +60 (yellow) to −60 (blue) using Eqs. (2)–(4). From the extracted values, color descriptors like hue, chroma, yellowness index and whiteness index were derived by computation [56], as indicated in Eqs. (5)–(8), respectively.

$$\mathrm{L}^* = \frac{100 \times L}{255} \tag{2}$$

$$\mathrm{a}^* = \frac{240 \times a}{255} - 120 \tag{3}$$

$$\mathrm{b}^* = \frac{240 \times b}{255} - 120 \tag{4}$$

$$\mathrm{C}^* = \sqrt{a^{*2}} + b^{*2} \tag{5}$$

$$\mathrm{h}^* = \tan^{-1} \frac{b^*}{a^*} \tag{6}$$

$$\text{Yellowness Index} = \frac{142.86 \times b^*}{L^*} \tag{7}$$

$$\text{Whiteness Index} = 100\sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \tag{8}$$

2.6 COMPUTER VISION SYSTEM

Nowadays the computer is routinely integrated to color measurement systems, by transferring the data collected from either a colorimeter or spectrophotometer to be transformed to XYZ, CIELAB, Hunter Lab or other color system provided by the software. Advancements in digital technology have also enabled use of scanner, camera and software for color measurement purposes. Following its origin in the 1960s, computer vision has experienced growth with its applications expanding in diverse fields not only for color measurements but also for process automations: medical diagnostic imaging; factory automation; remote sensing; forensics, robot guidance, etc. [23]. Computer vision and image analysis, are non-destructive and cost-effective techniques for sorting and grading of agricultural and food products during handling processes and processing operations [61].

2.6.1 APPLICATIONS OF COMPUTER VISION METHODS

Computer vision methods have wide applications in the food industry. Studies have been carried out to analyze visual characteristics of dairy, bakery, meat [79, 80] products, fruits and vegetables [5, 6, 80].

2.6.1.1 Dairy Products

Computer vision is used routinely in the quality assessment of yogurt, cheese, and pizza [19, 41, 74 and 84] and it is easy to analyze functional properties of Cheddar and Mozzarella cheeses with machine vision during cooking [86]. Images for each cheese slice before cooking and at periodic time intervals during cooking were captured and browning factor (BF) is used successfully to describe a reasonable index for cheese browning. Compared with conventional methods using colorimeters, the computer vision method is efficient and provides more information on the color change of cheese by making continuous measurement possible along with the advantage of handling uneven colored surfaces for cooked Mozzarella cheese. A computer vision system was coupled to a cheese vat, to measure color changes in the curd/whey mixture during syneresis [17]. Decreased white/yellow area ratio and increased RGB metric and Lab metric were observed to be caused by three factors intrinsic to curd syneresis: (a) the shrinkage of curd particles during syneresis, (b) the expulsion of whey from the curd during syneresis, and (c) the sinking of curd particles to the bottom of the vat during constant stirring. The study established the feasibility of computer vision and colorimeter measurements for monitoring syneresis. With the objective to determine color changes during storage of set type whole-fat and low-fat yogurts using a machine vision system (MVS) during storage, digitized images of yogurt acquired by digital color video camera, computer, and corresponding software and the obtained data were modeled with an artificial neural network (ANN) for prediction of shelf life [72]. The model was proposed as an alternative method to control the expiration date of yogurt shown in labeling and provide consumers with a safer food supply.

After applying the developed image-processing algorithm to recognize individual cheese shred and automatically measuring the shred length it was found that the algorithm recognized shreds well, even when they were overlapping. It was also reported that the shred length measurement errors were as low as 0.2% with a high of 10% in the worst case [50]. An objective method was developed and evaluated to measure the area occupied by calcium lactate crystals on the surface of naturally smoked Cheddar cheese samples using digital photography and analyzed using the Metamorph offline program. It was concluded that image analysis was well suited for evaluating changes in crystal coverage during cheese aging because of non-destructive type measurements with minimal rupture of cheese and good repeatability [60, 61]. Quantification of *Lactobaccilus spp.* in fermented milks grown in MRS agar was carried out by capturing digital color images through flatbed scanner [4].

Photoshop has been used to analyze the color for food samples, although the software was not originally designed for this purpose. However, it is already one of the most powerful software for color analysis, and the manufacturer and users are regularly making enhancements [21].

By using flatbed scanner and Adobe Photoshop the colors of espresso drink prepared with and without whey as a base ingredient were compared. Fresh coffee samples were scanned at a constant scanning resolution and R, G, B values of the scanned images were measured with Adobe Photoshop. It was found that color of whey coffee was almost similar to color of milk coffee. The suggested method for comparison of colors of product was safe and reliable [48]. The similar method was used for the study of color changes of *gulabjamuns* during frying [44]. Fried *gulabjaimuns* were scanned and using Adobe Photoshop software chroma, hue L a b values were computed. The study established the utility of computer vision system in measuring colors of heterogeneous products like *gulabjamun*.

2.6.1.2 Bakery Products

Color is the most desirable attribute in baking of food materials. The color of microwaved pizza can be effectively measured with simple digital imaging method. A high-resolution digital camera (2 mega-pixel or above) can be employed for capturing the color images of the food sample under proper lighting. Once the color images of the pizza samples were captured, the color can be analyzed qualitatively and quantitatively using Photoshop. The digital imaging method allows measurements and analyzes of the color of food surfaces that are adequate for food engineering research [90].

A computer aided reading system can be engaged for successful evaluation for grading of muffins based on the color. This was reported to improve the standardization and quantification of the inspection processes [1]. Physical features such as size, shape, dough color and fraction of top surface area of chocolate chip cookies can be estimated by using digital images [12].

A simple and new method for the evaluation of baking process on bread quality through the measurement of bread crust thickness, which was done based on the prediction of bread crust thickness by digital imaging and the L a b color system is available [32]. Porosity of white bread was measured by employing flatbed scanning which was reported as fast, easy to use, cheap, robust, and independent of external light conditions and with good accuracy [16].

2.6.1.3 Meat and Related Products

Color is the most important organoleptic characteristics and it influences the acceptability of the food product. The comparison of the instrumental color measurements of a Minolta colorimeter and a digital camera to measure color parameters is available in the literature. The parameters measured by digital camera were found to be more useful in predicting the meat quality [53]. This was due to the fact that the camera took measurements over the entire surface of samples and thus a more representative measurement was taken compared to colorimeter [42]. Computer vision was also used for assessment of fresh pork color [42, 78, 79].

Computer vision has been used to grade salmons replacing human labor [47]. Computer vision system is used to adjudge quality of salmons based on color score derived from RGB values of image taken by camera and L*a*b* color space. In the fish industry, despite the slow uptake, computer vision has been gradually gaining the necessary acceptance for quality evaluation applications [74, 24].

2.6.1.4 Fruits and Vegetables

In fruit processing industry color is the most important parameter hence it is demonstrated that the color of Golden apples can be measured using digitized video images and the apples could be ordered based on the CIE-color information and this was highly related to color ranking by a test panel [68].

Computer vision system involving measurement of peel color in terms of L, a, b values using histogram window method of Adobe Photoshop, standard L*, a*, b* values, the hue and chroma values along with the total color difference could be used to quantify overall changes of peel and pulp of mangoes, thus, enabling customization, standardization and storage studies of various fruits [65].

2.6.1.5 Chocolate

Chocolate blooming can be analyzed by measuring L*, a*, b* values, chroma (C*) values, whitening index (WI), hue (H°) percentage bloom and energy of Fourier using computer vision system and image analysis [5].

2.6.2 APPLICATION OF IMAGE ANALYSIS FOR DETECTION OF ADULTERATION

With increased expectations for food products of high quality and safety standards, the need for accurate, fast and objective quality determination of these characteristics in food products continues to grow.

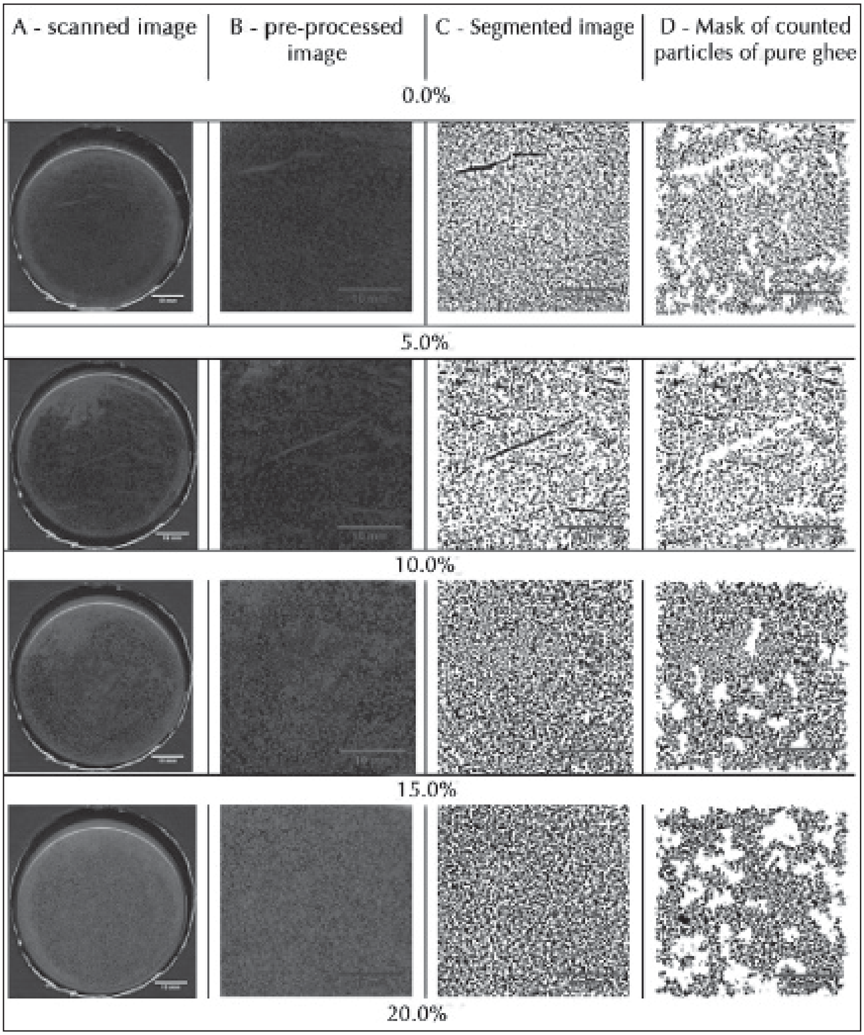

FIGURE 2.8 Progressive transition of the image during processing with the developed protocol.

Computer vision provides one alternative for an automated, non-destructive and cost-effective technique to accomplish these requirements. This inspection approach based on image analysis and processing has found a variety of different applications in the food industry. Considerable research has highlighted its potential for the inspection and grading of fruits and vegetables. Computer vision has been successfully adopted for the quality analysis of meat and fish, pizza, cheese, and bread. Likewise grain quality and characteristics have been examined by this technique [8].

Detection of minced meat fraudulently substituted with pork and vice versa can be detected by using multispectral imaging and multivariate data analysis with 98.48% overall correct classification [66].

Digital image analysis can analyze precisely and quickly a large number of ground coffee powders for detecting the adulteration in roast and ground coffee beans with coffee husk and straw, maize, brown sugar and soybean [67] also the impurities in virgin olive oil can be detected efficiently with computer vision system and pattern recognition [46].

The adulteration of cow ghee with vegetable fat can be detected by application of image analysis protocol. Controlled crystallization is the key factor in detecting the adulteration of ghee with image analysis. Number of parameters such as pixel intensity, particle count, particle diameter, fractal dimension, color parameters can be used as descriptors for detecting the adulteration. The sequence of operations such as conversion to 8-bit image, subtraction of background, enhancement of edges and segmentation may be carried out on the acquired image. Open source software such as ImageJ can be used to carry out image processing operations. Figure 2.8 shows the acquired and processed images of adulterated samples of ghee of various proportions [87]. The combination of derived parameters can be used for detection of adulteration of *ghee* [87].

2.7 CONCLUSIONS

Quality is an important responsibility of the stakeholders of food processing industry and there is need to develop rapid, non-destructive objective tools to evaluate and monitor the same during both online and offline modes. Image processing has been steadily gaining acceptance as a relevant methodology in quality control and assurance and has the potential to form an important component of this activity in the future.

2.8 SUMMARY

The major aim of this chapter is to provide an introduction to basic concepts and methodologies for digital image processing and to develop a confidence in readers that this tool can be implemented for studying the morphological, textural and color characteristics of the food material. This chapter includes information on: What is image? What is image processing? Purpose and scope of image processing; How to acquire images? Image acquisition systems; Image processing software; How to calibrate digital image? What are the basic steps in image processing? How to measure area, porosity, particle count, particle diameter, angle, intensity, etc.? What is texture? How it is different from traditional definition? Classification of image texture; How to measure texture? Importance of color in foods and how to measure it? These concepts are illustrated with practical examples.

KEYWORDS

- **adulteration**
- **angular second moment**
- **application of computer vision methods**
- **box counting method**
- **color chart**
- **color measurement**
- **color model**
- **colorimeter**
- **computer vision system**
- **contrast**
- **correlation**

- **CYMK model**
- **detection of adulteration**
- **digital camera**
- **digital image**
- **digital microscopy**
- **entropy**
- **fractal**
- **fractal dimension**
- ***ghee***
- **gradient based segmentation**
- **gray level co-occurrence matrix**
- **grey level**
- **hausdorff dimension**
- **illumination**
- **image acquisition devices**
- **image pre-processing**
- **image processing**
- **image segmentation**
- **image texture analysis**
- **inverse difference moment**
- **lab model**
- **model based texture**
- **munsell scale**
- **particle analysis**
- **particle size distribution**
- **pixel**
- **porosity**
- **region based segmentation**
- **RGB model**
- **scanner**
- **spectrophotometer**
- **statistical texture**

- **stimuli meter**
- **structural texture**
- **sum of squares**
- **texture**
- **thresholding based segmentation**
- **transform based texture**
- **void fraction**

REFERENCES

1. Abdullah, M. Z., Aziz, S. A., & Dos-Mohamed, A. M. (2000). Quality inspection of bakery products using a color-based machine vision system. *Journal of Food Quality*, *23*, 39–50.
2. Anonymous. (2002). *Adobe Systems*. Adobe Photoshop 7.0 User Guide, Adobe Systems Inc., San Jose, CA.
3. Barrette, A. H., & Peleg, M. (1995). Application of fractal analysis to food structure. *LWT*, *28*(6), 553–563.
4. Bell, R. W., & Webb, B. H. (1943). The relationship between high temperature fore-warming and the color and heat stability of evaporated milk of different solids content. *Journal of Dairy Science*, *26*, 579–585.
5. Borin, A., Ferrao, M. F., Mello, C., Cordi, L., Pataca, L. C. M., Duran, N., & Poppi, R. J. (2007). Quantification of *lactobaccilus* in fermented milks by multivariate image analysis with least square method vector machines. *Analytical and Bioanalytical Chemistry*, *387*(3), 1105–1112.
6. Briones, V., & Aguilera, J. M. (2005). Image Analysis of changes in surface color of chocolate. *Food Research International*, *38*(1), 87–94.
7. Brosnan, T., & Sun, D. W. (2002). Inspection and grading of agricultural and food products by computer vision systems: A Review. *Computers and Electronics in Agriculture*, *36*, 193–213.
8. Brosnan, T., & Sun, D. W. (2004). Improving quality inspection of food products by computer vision: A Review. *Journal of Food Engineering*, *61,* 3–16.
9. Caccamo, M., Melilli, C., Barbano, D. M., Portell, G., Marino, G., & Licitra, G. (2004b). Measurement of holes and mechanical openness in cheese by image analysis. *Journal of Dairy Science*, *87*, 739–748.
10. Curtin, D. P. (2007). A short course in sensors, pixels and image sizes. http://www.shortcourses.com/sensors/index.html.
11. Dalen, G. V. (2005). Characterization of rice using flat bed scanning and image analysis, Chapter 6. In: *Food Policy, Control and Research,* edited by Riley, A. P. New York: Nova Biomedical Books, pp. 149–186.

12. Davidson, V. J., Ryks, J., & Chu, T. (2001). Fuzzy models to predict consumer ratings for biscuits based on digital features. *IEEE Transactions on Fuzzy Systems, 9*(1), 62–67.
13. Dharaiya, C. N. (2006). *Quality Evaluation of Basundi Marketed in Bangalore City*. MTech Thesis, National Dairy Research Institute, Bangalore.
14. Du, C. J., & Sun, D. W. (2004). Recent developments in the applications of image processing techniques for food quality evaluation. *Trends in Food Science and Technology, 15*, 230–249.
15. Dziuba, J., Babuchowski, A., Smoczynski, M., & Smietana, Z. (1999). Fractal analysis of caseinate structure. *International Dairy Journal*, *9*, 287–292.
16. Esteller, M. S., Zancanaro, O., Palmeira, C. N. S., & Lannes, S. C. (2006). The effect of kefir addition on microstructure parameters and physical properties of porous white bread. *European Food Research and Technology, 222*(1–2), 26–31.
17. Everard, C. D., O'Callaghan, D. J., Fagan, C. C., O'Donnell, C. P., Castillo, M., & Payne, F. A. (2007). Computer vision and color measurement techniques for inline monitoring of cheese curd syneresis. *Journal of Dairy Science*, *90*(3), 3162–3170.
18. Francis, F. J., & Clydesdale, F. M. (1975). *Food Colorimetry – Theory and Applications*. AVI Publishing Co. Westport, CT, USA.
19. Gerrard, D. E., Gao, X., & Tan, J. (1996). Beef marbling and color score determination by image processing. *Journal of Food Science*, *61*(1), 145–148.
20. Gonzalez, R. C., & Woods, R. E. (2008). *Digital Image Processing*, 3rd edition, Prentice Hall, London, p. 24.
21. González-Tomás, L., & Costell, E. (2006). Relation between consumers' perceptions of color and texture of dairy desserts and instrumental measurements using a generalized procrustes analysis. *Journal of Dairy Science, 89*, 4511–4519.
22. Goodrum, J. W., & Elster, R. T. (1992). Machine vision for crack detection in rotating eggs. *Transactions of the ASAE*, *35*, 1323–1328.
23. Gunasekaran, S. (1996). Computer vision technology for food quality assurance. *Trends in Food Science and Technology*, *7*, 245–256.
24. Gunnlaugsson, G. A. (1997). Vision technology, intelligent fish processing systems. In: *Seafood from Producer to Consumer, Integrated Approach to Quality*, edited by Luten, J. B., Børresen, T., & Oehlenschläger, J., Elsevier Science, The Netherlands, pp. 351–359.
25. Hareesh, K. S., & Narendra, V. G. (2010). Prospects of computer vision automated grading and sorting systems in agricultural and food products for quality evaluation. *International Journal of Computer Applications*, *1*(4), 1–12.
26. Imre, A. R., & Bogaert, J. (2004). The fractal dimension as a measure of the quality habitats. *Acta Biotheoretica*, *52*, 41–56.
27. Ingrassia, R., Costa, J. P., Hindalgo, M. E., Canales, M. M., Castellini, H. C., Riquelme, B., & Risso, P. (2013). Application of a digital image procedure to evaluate microstructure of caseinate and soy protein acid gels. *Food Science and Technology*, *53*, 120–127.
28. Jacobs, M. B. (1999). *The Chemical Analysis of Food and Food Products*. Third Edition, CSB Publications and Distributors, New Delhi.
29. Jahne, B. (2004). *Practical Handbook on Image Processing for Scientific and Technical Applications*, II edition. CRC Press, p.34.

30. Jia, P., Evans, M. D., & Ghate, S. R. (1996). Catfish feature identification via computer vision. *Transactions of the ASAE*, *39*, 1923–1931.
31. Joshi, P. (2004). Color measurement of foods by color reflectance. In: *Color in Food – Improving Quality*, edited by MacDougall, D. B., Woodhead Publishing Limited, England, pp. 81–114.
32. Jusoh, Y. M., China, N. L., Yusof, Y. A., & Rahman, R. A. (2009). Bread crust thickness measurement using digital imaging and Lab color systems. *Journal of Food Engineering*, *94*(3), 366–371.
33. Karim, N., Wilson, T. V., & Gurevich, G. (2006). How Digital Camera Works. http://electronics.howstuffworks.com/camerasphotography/digital/digital-camera.htm.
34. Kress-Rogers, E., & Christopher, J. B. B. (2001). *Instrumentation and Sensors for the Food Industry*. Woodhead Publishing Ltd., Cambridge, England.
35. Kuehni, R. G. (2002). The early development of the Munsell system. Second Edition, *Color Research and Application, 27*(1), 20–27.
36. Lawless, H. T., & Heymann, H. (1998). *Sensory Evaluation of Food: Principle and Practices*. Chapman and Hall, New York, pp. 406–429.
37. Leemans, V., Magein, H., & Destain, M. F. (1999). Defect segmentation on 'Jonagold' apples using color vision and a Bayesian classification method. *Computers and Electronics in Agriculture*, *23*, 43–53.
38. Li, Q., Xie, Q., Yu, S., & Gao, Q. (2014). Application of digital image analysis method to study the gelatinization process of starch/ sodium chloride solution system. *Food Hydrocollides*, *35*, 392–402.
39. Li, Q. Z., & Wang, M. H. (1999). Development and prospect of real time fruit grading technique based on computer vision. *Transactions of the Chinese Society of Agricultural Machinery*, *30*(6), 1–7.
40. Liang, B., Sebright, J. L., Shi, Y., Hartel, R. W., & Perepezko, J. H. (2006). Approaches to quantification of microstructure for model lipid systems. *Journal of the American Oil Chemists Society*, *83*(5), 389–399.
41. Locht, P., Thomsen, K., & Mikkelsen, P. (1997). Full color image analysis as a tool for quality control and process development in the food industry. ASAE Annual International Meeting, Paper no. 9733006, ASAE, 2950 Niles Road, St. Joseph, Michigan, 49085–9659, USA.
42. Lua, J., Tan, P., Shatadal, P., & Gerrard, D. E. (2000). Evaluation of pork color by using computer vision. *Meat science*, *56*(1), 57–60.
43. Maerz, A., & Paul, M. R. (1950). Dictionary of color. Second edition, McGraw-Hill, Inc., New York, USA.
44. Magdaline, E. E. F., Menon, R. R., Heartwin, A. P., Rao, J. K., & Surendranath, B. (2009). Image analysis and kinetics of color changes during frying of *gulabjamuns*. Poster paper presented at XX Indian Convention of Food Scientists and Technologists, 21–23 Dec., Bangalore. Souvenir AD-38, p.9.
45. Marangoni, A. G., (2002). The nature of fractality in fat crystal networks. *Trends in Food Science and Technology*, *13*, 37–47.
46. Marchal, P. C., Gila, D. M., Garcia, J. G., & Ortega, G. J. (2013). Expert system based on computer vision to estimate the content of impurities in olive oil samples. *Journal of Food Engineering, 119*, 220–228.

47. Misimi, E., Erikson, U., & Skavhaug, A. (2008). Quality grading of Atlantic salmon (*Salmo salar*) by computer vision. *Journal of Food Science*, *73*(5), 211–217.
48. Nawale, P. K., Vyawahare, A. S., Aravindakshan, P., & Rao, J. K. (2009). Dairy based espresso drinks preparation using whey as a base ingredient. Poster paper presented at XX Indian Convention of Food Scientists and Technologists, 21–23 Dec., Bangalore. Souvenir AD-38, 14.
49. Nelson, V. (1948). The spectrophotometric determination of the color of milk. *Journal of Dairy Science*, *31*(6), 409–414.
50. Ni, H., & Gunasekaran, S. (1995). A computer vision system for determining quality of cheese shreds. *In: Food Processing Automation IV*, Proceedings of the FPAC Conference, ASAE, 2950 Niles Road, St. Joseph, Michigan 49085–9659, USA.
51. Novini, A. (1990). Fundamentals of machine vision component selection, *In: Food Processing Automation II*- Proceedings of the 1990 conference, Lexinton, KY: ASAE, p.60.
52. Ogava, H., Nasu, H., Takeshige, M., Funabashi, H., Saito, M., & Matsuoka, H. (2012). Noise free accurate count of microbial colonies by time-lapse shadow image analysis. *Journal of Microbial Methods*, *91*, 420–428.
53. O'Sullivan, M. G., Byrne, D. V., Martens, H., Gidskehaug, L. H., Andersen, H. J., & Martens, M. (2003). Evaluation of pork color, prediction of visual sensory quality of meat from instrumental and computer vision methods of color analysis. *Meat Science*, *65*(2), 909–918.
54. Panigrahi, S., Misra, M. K., Bern, C., & Marley, S. (1995). Background segmentation and dimensional measurement of corn germplasm. *Transactions of the ASAE*, *38*, 291–297.
55. Papadakis, S. E., Abdul-Malek, S., Kamden, R. E., & Yam, K. L. (2000). A versatile and inexpensive technique for measuring color of foods. *Food Technology*, *54*(12), 48–51.
56. Pathare, P. B., Opara, U. L., & Al-Said, F. A. (2013). Color measurement and analysis in fresh and processed foods, A Review. *Food Bioprocess Technology*. *6*, 36–60.
57. Pillonel, L., Dufour, E., Schaller, E., Bosset, J. O., Baerdemaeker, J. D., & Karoui, R. (2007). Prediction of color of European Emmental cheeses by using near infrared spectroscopy, a feasibility study. *European Food Research and Technology*, *226*(1–2), 63–69.
58. Poynton, C. A. (2003). Digital video and HDTV, algorithms and interfaces. Morgan Kaufmann. ISBN 1558607927. http://books.google.com/books.
59. Quevedo, R. A., Aguilera, J. M., & Pedreschi, F. (2008). Color of salmon filets by computer vision and sensory panel. Food and Bioprocess Technology, http://www.springerlink.com/content/653w 7054m870rx41/.
60. Quevedo, R. A., Carlos, L. G., Aguilera, J. M., & Cadoche, L. (2002). Description of food surfaces and microstructural changes using fractal image texture analysis. *Journal of Food Engineering*, *53*, 361–371.
61. Rajbhandari, P., & Kindstedt, P. S. (2005). Development and application of image analysis to quantify calcium lactate crystals on the surface of smoked Cheddar cheese. *Journal of Dairy Science, 88*(12), 4157–4164.
62. Rajbhandari, P., & Kindstedt, P. S. (2008). Characterization of calcium lactate crystals on cheddar cheese by image analysis. Journal of Dairy Science, *91*, 2190–2195.

63. Randall, D. L. (1997). Instruments for the color management. In: *Color Technology in the Textile Industry*. Second Edition, American Association of Textile Chemist and Colorists, pp. 11–17.
64. Ranganna, S. (2002). *Handbook of Analysis and Quality Control for Fruits and Vegetable Products*. Second Edition, Tata McGraw Hill Publishing Company, New Delhi.
65. Ravindra, M. R., & Goswami, T. K. (2008). Comparative performance of pre-cooling methods for storage of mango. *Journal of Food Process Engineering*, *31*(3), 355–371.
66. Ropadi, A. I., Pavlidis, D. E., Mohareb, F., Panagou, E. Z., & Nychas, G. J. E. (2015). Multispectral image analysis approach to detect adulteration of beef and pork in raw meats. *Food Research International*, *67*, 12–18.
67. Sano, E. E., Assad, E. D., Cunha, S. A. R., Correa, T. B. S., & Rodrigues, H. R. (2003). Quantifying adulteration in roast coffee powders by digital image processing. *Journal of Food Quality*, *26*, 123–134.
68. Schrevens, E., & Raeymaeckers, L. (2005). Color characterization of golden delicious apples using digital image processing. *Acta Horticulturae*, 304, 159–166.
69. Shamsgovara, A. (2012). Analytic and numerical calculations of fractal dimensions. Department of Mathematics, Royal Institute of Technology, KTH, pp. 3–45.
70. Shishkin, Y. L., Dmitrienko, S. G., Medvedeva, O. M., Badakova, S. A., & Pyatkova, L. N. (2004). Use of a scanner and digital image – processing software for the quantification of adsorbed substances. *Journal of Analytical Chemistry*, *59*(2), 102–106.
71. So, J. D., & Wheaton, F. W. (1996). Computer vision applied to detection of oyster hinge lines. *Transactions of the ASAE*, *39*, 1557–1566.
72. Sofu, A., & Ekinci, F. Y. (2007). Estimation of storage time of yogurt with artificialneural network modeling. *Journal of Dairy Science*, *90*, 3118–3125.
73. Solah, V. A., Staines, V., Honda, S., & Limley, H. A. (2007). Measurement of milk color and composition, effect of dietary intervention on Western Australian Holstein-Friesian cow's milk quality. *Journal Food Science, 72*(8), 560–566.
74. Strachan, N. J. C., & Murray, C. K. (1991). Image analysis in the fish and fish industries. In: *Fish Quality Control by Computer Vision*, edited by Pau, L. F., & Olafsson, R. Marcel Dekker, New York, USA, pp. 209–223.
75. Sun, D. W. (2000). Inspecting pizza topping percentage and distribution by a computer vision method. *Journal of Food Engineering*, *44*, 245–249.
76. Sun, D. W., & Brosnan, T. (2003). Pizza quality evaluation using computer vision-part I pizza base and sauce spread. *Journal of Food Engineering*, *57*, 81–89.
77. Sutheerawattananonda, M., Fulcher, R. G., Martin, F. B., & Bastian, E. D. (1997). Fluorescence image analysis of process cheese manufactured with trisodium citrate and sodium chloride. *Journal of Dairy Science*, *80*(4), 620–627.
78. Tan, F. J., Morgan, M. T., Ludas, L. I., Forrest, J. C., & Gerrard, D. E. (2000). Assessment of fresh pork color with color machine vision. *Journal of Animal Science*, *78*, 3078–3085.
79. Tan, F. J. (2004). Meat quality evaluation by computer vision. *Journal of Food Engineering*, *61*, 27–35.
80. Tao, Y., Heinemann, P. H., Varghese, Z., Morrow, C. T., & Sommer, H. J. (1995). Machine vision for color inspection of potatoes and apples. *Transactions of the ASAE* *38*(5), 1555–1561.

81. Tillett, R. D. (1990). Image analysis for agricultural processes. Division Note DN 1585, Silsoe Research Institute.
82. Timmerman (1998). Computer vision system for online sorting of pot plants based on learning techniques. *Acta Horticulturae*, *42*(1), 91–98.
83. Torres, I. C., Ruio, J. M. A., & Ipsen, R. (2012). Using fractal image analysis to characterize microstructure of low-fat stirred yogurt manufactured with microparticulated whey protein. *Journal of Food Engineering*, *109*, 721–729.
84. Tyson, J. (2001). How scanners work. http://HowStuffWorks.com.
85. Wang, H. H., & Sun, D. W. (2002a). Melting characteristics of cheese, analysis of effects of cooking conditions using computer vision technology. *Journal of Food Engineering*, *51*(4), 305–310.
86. Wang, H. H., & Sun, D. W. (2002b). Correlation between cheese meltability determined with a computer vision method and with Arnott and Schreiber tests. *Journal of Food Science*, *67*(2), 745–749.
87. Wasnik, P. G. (2015). *Development of Process Protocol for Image Analysis and Its Application for Detection of Cow Ghee with Vegetable Fat.* PhD thesis, ICAR-National Dairy Research Institute, Karnal, India.
88. Webb, B. H., & Holm, G. E. (1930). Color of evaporated milks. *Journal of Dairy Science, 13*, 25–39.
89. Wu, Y., Lin, Q., Chen, Z., Wu, W., & Xiao, H. (2012). Fractal dimension of the retrogradation of rice starch by digital image processing. *Journal of Food Engineering, 109*, 182–187.
90. Yam, K. L., & Papadakis, S. (2004). A simple digital imaging method for measuring and analyzing color of food surfaces. *Journal of Food Engineering*, *61*(1), 137–142.
91. Yang, Q. (1994). An approach to apple surface feature detection by machine vision. *Computers and Electronics in Agriculture*, *11*, 249–264.
92. Zheng, C. X., Da-Wen Sun and Zheng, L. Y. (2006). Recent Developments and Applications of Image Features for Food Quality Evaluation and Inspection: A Review. *Trends in Food Science and Technology*, *17*(12), 642–655.
93. Zion, B., Chen, P., & McCarthy, M. J. (1995). Detection of bruises in magnetic resonance images of apples. *Computers and Electronics in Agriculture*, *13*, 289–299.

CHAPTER 3

PASSIVATION: A METHOD TO ENSURE QUALITY OF DAIRY AND FOOD PROCESSING EQUIPMENT

GEETESH SINHA, KRISHAN DEWANGAN, and A. K. AGRAWAL

CONTENTS

3.1 INTRODUCTION

We are always concerned about the quality of processed food but it cannot be guaranteed until quality of processing equipment is ensured. The manufacturers and users of modern dairy and food processing equipment demand the use of stainless steel (SS) as the predominant material of construction. SS has become the standard material of construction because of its ability to maintain a high level of performance, while keeping corrosion to a minimum [14].

The metals used for food contact surfaces must be non-toxic, non-tainting, insoluble (in food), highly resistant to corrosion, easy to clean and keep bright, light yet strong, good agent of heat transfer, good in appearance throughout life, low in cost, non-absorbent and durable, etc. The metal SS possesses most of these properties. Therefore, generally food-processing equipment are made of SS. These are certain alloys of iron and chromium, which are highly resistant to corrosion. These alloys sometimes contain nickel and small percentage of molybdenum, tungsten and copper. This complex group of alloys is known as stainless steel. It can be welded, forged, rolled and machined [9]. Although unwantedly, it may be subjected to some contamination/ abnormalities due to mill scales, iron particle impregnation because of hot and cold rolling, pit corrosion, stress corrosion, inter granular corrosion in the *heat affected zone* (HAZ) and ruptured passive layer, etc. The presence of these contaminations/ impurities in SS equipment may adversely affect the metallurgical or sanitary conditions or stability of a surface, or contaminate a process fluid [15].

Passivation is an important surface treatment that helps assure the successful corrosion – resistant performance of SS used for product – contact surface (i.e., tubing/piping, tanks and machined parts used in pumps, valves, homogenizers, de-aerators, process-monitoring instruments, flow meters, ingredient feeders, blenders mixers, dryer pasteurizers, heat exchangers, conveyors and foreign body detectors) [6, 14]. It is performed when free iron, oxide scale, rust, iron particles, metal chips or other nonvolatile deposits might adversely affect the metallurgical or sanitary conditions or stability of the surface, the mechanical operation of a part, component or system, or contaminate the process fluid [15].

This chapter describes the passivation process to enhance the quality of dairy products.

3.2 DAIRY AND FOOD PROCESSING EQUIPMENT: USE OF STAINLESS STEEL IN MANUFACTURING

The SS is the steel that is correctly heat treated and finished, resists oxidation and corrosive attack from corrosive media. The SS has important application in food processing plant due to its marked resistance to corrosion by the atmosphere and a range of acid and alkaline solutions. There are fairly different distinct types of stainless steels having large percentage of chromium (4–22%) and sometimes of nickel (0–26%). The stainless steels are broadly grouped into three groups according to their microstructure namely: (i) martensite; (ii) ferrite; and (iii) austenite steels. The austenite SS is probably most important group of SS alloys. The main characteristics of this type are high ductility, work hardening ability, good corrosion resistance and high tensile properties. These alloys are highly resistant to many acids and cold nitric acid. These steels are used in manufacture of vats and pipes that are used in the dairy and food plants. The food processing equipment like kettle, tank, household items like cooking utensils and dairy utensils like milk can are some applications of this type of steels [3, 5].

The SS possesses favorable engineering properties like hardness, malleability and ductility. It can be fabricated easily to any size and shape. It can be easily welded although cannot be soldered. The equipment made with SS can be imparted high degree of surface finish (mirror polish) and therefore attractive in appearance. The SS equipment last longer on continuous service. They are actually non-toxic, non-tainting and have no influence on product quality in regard to flavor. The metallic surface of these equipment must be insoluble that comes in contact with both products and cleaning solutions. The SS equipment surfaces particularly product contact surfaces are easy to clean and sterilize [5].

3.3 NEED OF PASSIVATION OF FOOD PROCESSING EQUIPMENT MADE OF STAINLESS STEEL

Particles of iron or tool steel or abrasive particles may be embedded in or smeared on or into the surfaces of SS components during: handling and processing such as rolling, forming, machining, pressing, tumbling and lapping. If allowed to remain, these particles may corrode and produce rust spots on the SS, due to the formation of a galvanic couple between two dissimilar metals that can promote a corrosive reaction. To dissolve the embedded or smeared iron and prevent this condition, as well as restore the original corrosion-resistant surface, semi-finished or finished parts need to be given a *passivation* treatment [1].

Food Scientists/engineers alike are somewhat lack of knowledge when it comes to the relationship between corrosion resistant (stainless) steel and chemical passivation. Some believe it is effective because it is a cleaning process. Others credit the enhanced corrosion resistant properties to the thin, transparent oxide film resulting from passivation. Verification tests, including copper sulfate immersion, and accelerated corrosion tests, such as salt spray, high humidity, and water immersion, undisputedly confirm the effectiveness of passivation. Advanced material engineers in aerospace, electronics, medical, and similar high-tech industries have utilized passivation technology for many years. Their applications demand the maximum performance from components manufactured from stainless steels, and they realize that passivation is one of the most effective methods of achieving the desired results [4].

3.4 PICKLING

Pickling is typically performed to remove tightly adherent oxide films resulting from hot- forming, heat-treating, welding and other high temperature operations. Welding or heat treatment often produces complex oxides that can vary in color. All these oxides are generally referred to as “scale” and must be removed. Pickling is pre-cursor step to passivation. Prior to pickling, the heavy surface soils such as oil, grease, buffing compounds, drawing compounds, some scale, heavy rust, dye and paint markings, tape, adhesive residue and other foreign substances must be removed. This step may be accomplished by the use of alkaline cleaners, solvent cleaning, vapor degreasing, ultrasonic cleaning, steam cleaning, water-jetting, or other mechanical cleaning. Pre-cleaning is not required if oxide or scale is the only soil on the surface [2].

Where applicable, alternative mechanical methods such as blasting, shot peening, tumbling, and wheel abrading may also be performed. Abrasives containing iron should not be used. In many cases, pickling of stainless steels is performed in two steps: one for softening the scale and one for final scale removal. Over-pickling, under-pickling and pitting usually are direct results of lack of control over process variables including acid concentrations, solution temperature and contact time. The processes of pickling and passivation must be clearly distinguished. The process specified is to "*pickle and passivate* (a two-step method)" in order to create a surface on SS that would be resistant to corrosion. *Pickling* (or chemical de-scaling) is done to remove scale while *passivation* is done to make the surface more passive and corrosion resistant. Passivation is performed on clean stainless steel, provided the surface has been thoroughly cleaned or de-scaled [13].

3.5 WHAT IS PASSIVATION?

According to ASTM-A-380, passivation is "*the removal of exogenous iron or iron compounds from the surface of a stainless steel by means of a chemical dissolution, most typically by a treatment with an acid solution that will remove the surface contamination but will not significantly affect the stainless steel itself.*" In addition, it also describes passivation as "*the chemical treatment of a stainless steel with a mild oxidant, such as a nitric acid solution, for the purpose of enhancing the spontaneous formation of the protective passive film*" [1].

In layman's terms, the passivation process removes "free iron" contamination left behind on the surface of the SS as a result of machining and fabricating processes. These contaminants are potential corrosion sites, which if not removed, result in premature corrosion and ultimately result in deterioration of the component. In addition, the passivation process facilitates the formation of a very thin, transparent oxide film, which protects the SS from "selective" oxidation (corrosion). *Passivation* is the formation of a hard non-reactive surface film that inhibits further corrosion. This layer is usually an oxide or nitride that is a few atoms thick [1, 10].

3.6 EFFECTS OF PASSIVATION

Passivation is actually a comprehensive term denoted to describe a range of processes for achieving the desired effect on stainless steel. Therefore, it is necessary to encompass the various effects covered precisely by passivation [6, 7].

1. Passivation is the process by which SS will spontaneously form a chemically inactive surface when exposed to air or other oxygen-containing environments. Steels containing more than 11% Chromium are capable of forming an invisible, inert or passive, self-repairing oxide film on their surface. It is this passive layer that gives stainless steels their corrosion resistance. If a SS surface is scratched, then more chromium is exposed which reacts with oxygen allowing the passive layer to reform.
2. Passivation is the chemical treatment of a SS surface with a mild oxidant such as citric acid passivation solution. This process is to accelerate the process noted above in step 1.
3. Passivation is the removal of exogenous iron or iron compounds from the surface of SS by means of a chemical dissolution, most typically by a treatment with a citric acid passivation solution that will remove the surface contamination but will not significantly affect the SS itself.
4. Passivation is also accomplished by electropolishing, which is an electrochemical process that is a super passivator of SS and results in a more passive surface than the other methods mentioned above.

3.7 STEPS IN PASSIVATION

3.7.1 SURFACE CLEANING, CHEMICAL CLEANING, AND DEGREASING

This stage allows pickling and passivation chemicals to come in contact with metal surface which has to passivate.

3.7.2 PICKLING PROCESS

This stage allows to itch metal surface uniformly, which is controlled itching. In this stage metal surface gets activated uniformly.

3.7.3 PASSIVATION PROCESS

This stage eliminates corrosion susceptibility of surface of the metals creating uniform passive layer. Chemical surface conversion takes place. Surface becomes passive for further air-oxidation.

3.7.4 CONFIRMATION OF PASSIVATION

In this stage, the passivation effectiveness must be confirmed by one or more specified test practices to qualify for certification.

3.8 HOW IS THE PASSIVATION PROCESS PERFORMED?

The process typically begins with a thorough cleaning cycle. It is intended to remove oils, greases, forming compounds, lubricants, coolants, cutting fluids, and other undesirable organic and metallic residue left behind as a result of fabrication and machining processes (Figure 3.1). General degreasing and cleaning can be accomplished by a variety of commonly accepted methods, including vapor degreasing, solvent cleaning, and alkaline soaking. After removal of the organic and metallic residues, the parts are placed into the appropriate passivation solution. Although there are many variations of passivating solutions, yet the overwhelming choice is still the nitric acid based solutions. Recently, there has been substantial research performed to develop alternative processes and solutions that are more "environmentally friendly," yet equally effective. Although alternative solutions containing citric acid and other types of proprietary chemistry are available, they have not been as widely accepted commercially as nitric acid based solutions [11].

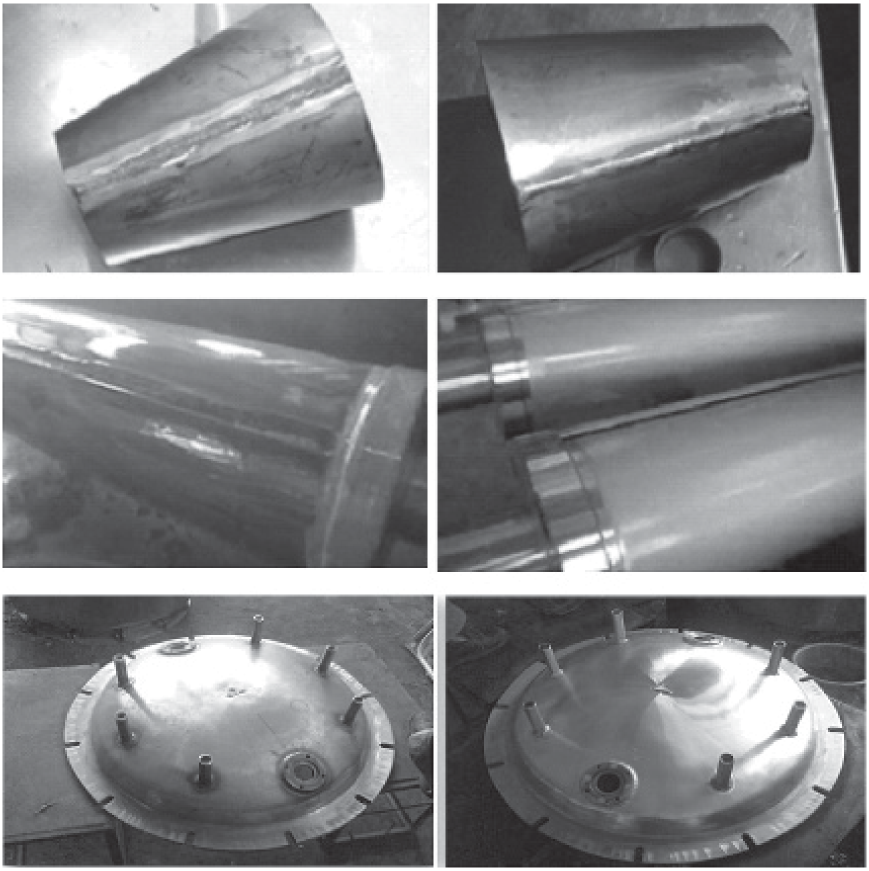

FIGURE 3.1 Utensils or parts of equipment before (left) and after (right) passivation.

The three major variables that must be considered and controlled for the passivation process selection are time, temperature, and concentration. Typical immersion times are between 20 and 120 minutes. Typical bath temperatures range between room temperature and 70°C. Nitric acid concentrations in the 20–50% by volume range are generally specified. Many specifications include the use of sodium dichromate in the passivation solution, or as a post passivation rinse, to aid in the formation of a chromic oxide film. Careful solution control, including water purity, ppm (parts per million) of metallic impurities, and chemical maintenance, are crucial for success. The type of SS being processed is the determining factor when selecting the most effective passivation process. Bath selection (time, temperature, and concentration) is a function of the type of alloy being processed. A thorough knowledge of the material types and passivation processes is paramount to achieving the desired results. Conversely, improper bath and process selection and/or process control will produce unacceptable results; and in extreme cases, can lead to catastrophic failure, including extreme pitting, etching and/or total dissolution of the entire component [7, 10, 14, 15].

3.9 APPLICATION METHOD: USER FRIENDLY APPROACH

The pickling and passivation chemical is available in ready to use formulation for application on equipment by any one of the following methods:

1. by dipping;
2. by spraying;
3. by swabbing with lint free cloth; and
4. by immersion.

The solution should be used at room temperature.

3.10 PROCESS OF PASSIVATION

The process calls for the following sequence:

1. Degreasing the product/plant (swabbing or spray).
2. Removal of welding seams.
3. Spray/brush/swab/immerse the equipment by pickling passivation chemical.
4. During application of the product, let the solution react with the surface for about 15–20 minutes.
5. Spray wash with normal water-water rinsing (120 bars).
6. Drying.

3.11 PRECAUTIONS DURING PASSIVATION

Passivation should only be performed by trained, experienced technicians familiar with the potential hazards associated with the science.

Safety practices must be fully understood when handling passivation chemicals. Special boots, gloves, aprons and other safety equipment must be utilized. Tanks, heaters and ventilation, as well as baskets and racks, must be appropriately engineered to perform the process. Iron or steel parts or equipment must never be introduced to the process, or the results can be devastating [11].

3.12 SPECIFICATIONS AND VERIFICATION TESTING OF PASSIVATION

There are few generally accepted industry specifications available for reference when choosing a passivation process. They offer time, temperature, and concentration information, and subsequent testing requirements to validate the effectiveness of the process. Many large corporations have developed internal specifications to control their unique requirements regarding passivation and verification testing. Regardless of the situation, it is usually prudent to reference a proven procedure when requesting passivation [1]. The most commonly referenced industry specifications are ASTMA-967 and ASTM-A-380. Both standards are well written, well-defined documents, which provide guidance on the entire process, from manufacturing to final testing requirements.

One of the most commonly specified verification tests is the copper sulfate test. Passivated parts are immersed in a copper sulfate solution for 6 minutes, rinsed, and visually examined. Any copper (pink) color indicates the presence of free iron, and the test is considered unacceptable. Other validation tests include a 2 hour salt spray or 24 hour high-humidity test. These tests are performed by placing passivated parts in a highly controlled chamber, which creates an accelerated corrosive environment. After subjecting the test pieces to the corrosive atmosphere for the prescribed exposure periods, the parts are removed and evaluated [1, 8, 12].

3.13 SUCCESSFUL PASSIVATION: RECOMMENDATIONS TO FOOD PROCESSING EQUIPMENT MANUFACTURERS

It is seen that most of the equipment manufacturers use the passivation solution for only the weld pool line or the heat dissipation areas. But that does not ensure from risk of corrosion since the pitting on the remaining surface remain untreated as well as the corrosion susceptible gray zone remains forever. The simple spatters of the grinding also get indented into the surface and it causes the seeding for the corrosion. The following practices will reduce gross contamination during manufacturing and increase the chances of successful passivation and test results:

- Never use grinding wheels, sanding materials, or wire brushes made of iron, iron oxide, steel, zinc, or other undesirable materials that may cause contamination of the SS surface.
- Grinding wheels, sanding wheels, and wire brushes that have been previously used on other metals should not be used on stainless steel.
- The use of carbide or other non-metallic tooling is recommended whenever possible.
- Use only clean, unused abrasives such as glass beads or iron-free silica or alumina sand for abrasive blasting. Never use steel shot or grit, or abrasives which have been used to blast other materials.
- Thorough cleaning prior to any thermal processing is critical. Stress relieving, annealing, drawing, or other hot-forming processes can actually draw surface contaminants deeper into the substrate, making them almost impossible to remove during passivation.
- Care should be taken during all thermal processes to avoid the formation of discoloration (oxides). Passivation is not designed to remove discoloration, and will not penetrate heavy oxide layers. In extreme situations, additional pickling and descaling operations are required prior to passivation to remove the discoloration. Controlled atmosphere ovens are highly recommended for all thermal processes to reduce airborne contamination and prevent oxides from developing [14].

3.14 CONCLUSIONS

During equipment manufacturing, machining, fabricating and heat-treating practices can substantially affect the corrosion resistance of the component. The passivation will enhance the corrosion resistance of stainless steels, but to realize the maximum performance from these high-tech alloys, all parties involved with manufacturing must understand their responsibility in maintaining the integrity of the material throughout the process.

Pickling or chemical descaling is but one of several pretreatment steps available for preparing an article for further processing such as passivation or electro-polishing, or to perform a superior cleaning operation of welded structures. Passivation process is both an art and a science. Passivation is a process performed to make a surface passive, for example, a surface film is created that causes the surface to lose its chemical reactivity. Passivation unipotentializes the SS with the oxygen absorbed by the metal surface, creating a monomolecular oxide film. Passivation can result in the very much-desired low corrosion rate of the metal.

3.15 SUMMARY

Pickling and passivation is used to reduce contamination and corrosion on stainless steel. It is the innovation technology to change the surface area of SS for strong, better and long serving. Normally dairy and food equipment manufacturing industry uses SS of grades of AISI 304, 304L, 316, 316L, etc., as material of construction. The raw pieces of SS materials are cut, rolled, welded and brazed, in order to give final shape to the food processing equipment. During fabrication, the materials develop several metallurgical changes which may be responsible for contamination of the surface of final equipment. It is therefore absolutely essential to ensure pickling and passivation of SS plants and equipment. Otherwise contamination will come in contact with the metal and ultimately result in the contamination of food product.

KEYWORDS

- **dairy processing equipment**
- **electro polishing**
- **food processing equipment**
- **galvanization**
- **passivation**
- **pickling**
- **stainless steel**

REFERENCES

1. American Society for Testing and Materials (ASTM), (1996). *Cleaning and Descalling Stainless Steel Parts, Equipment and System (ASTM-A-380)*. ASTM, West Conshohocken, PA, USA.
2. Anonymous (1986). *Pickling Handbook Surface Treatment of Stainless Steels*. Voestalpine Bohler Welding GmbH, p. 12.
3. Anonymous, (1988). *Cleaning and Descaling Stainless Steels*. A Designers Handbook Series by Nickel Development Institute.
4. Bornmyr, A., Toesch, J., & Winkler, F. (2009). *Pickling Handbook: Surface Treatment of Stainless Steels*. Böhler Welding GmbH.
5. Holah, J. (2000). *Food Processing Equipment Design and Cleanability*. The National Food Centre, Ireland.
6. http://en.wikipedia.org/wiki/Passivation.
7. http://en.wikipedia.org/wiki/Passivation (chemistry).
8. http://www.astm.org/Standards/A380.htm.
9. http://www.astropak.com/ultra-pass-passivation.php.
10. http://www.delstar.com/passivating.htm.
11. http://www.electrohio.com/Finishing/Passivation/Passivation.htm.
12. http://www.passivationindia.com.
13. http://www.picklingandpassivation.com/index.html.
14. Maller, R. R. (1998). Passivation of stainless steel. *Trends in Food Science and Technology, 9*, 28–32.
15. Tuthill. H. (2002). *Stainless Steels and Specialty Alloys for Modern Pulp and Paper Mills*. Reference Book Series No 11-025 by Nickel Development Institute, p. 139.

CHAPTER 4

TECHNOLOGY OF PROTEIN RICH VEGETABLE BASED FORMULATED FOODS

DINESH CHANDRA RAI and ASHOK KUMAR YADAV

CONTENTS

4.1 INTRODUCTION

Formulated foods are foods that are prepared or manufactured according to plan from individual components, to yield products having specified physical, chemical and functional properties. These are foods that have been taken apart and put together in a new form. Designed, engineered or formulated from ingredients, they may or may not include additives, vitamins and minerals. Formulated foods are engineered foods and are same as fabricated foods. There are mainly two types of formulated foods:

- Those designed to simulate natural counterparts and are referred as "analogs" such as meat and dairy analogs.
- Those no prior counterparts and are manufactured for specific functional properties by mixing two or more food products.

The food processing industry is giving increased emphasis to the production and utilization of alternate protein isolate products as functional and nutritional ingredients in an expanding number of formulated food products. Alternate protein sources such as soy and other vegetable proteins offer additional flexibility in formulating foods due to their economics, availability, functionality and nutritional properties. It also needs for developing soy and vegetable protein isolates with improved flavor, color and functionality for producing simulated dairy foods. It also considers alternative technologies for incorporating soy and vegetable proteins into the formulation so that they may function properly for forming stable solutions, emulsions, foams and gels that resemble those in their natural dairy food counterparts. Many types of formulated foods are now available and selected categories are shown Table 4.1.

Consumers are now more concerned on nutritious, healthy and natural foods [4]. Fruit and vegetable blends present numerous advantages, such as flavor and nutritional added-value [24]. Blended beverage has appeared as a good option of nutritionally improved product with good sensory properties [5, 11, 17]. Some of the Indian traditional formulated foods are listed below:

- Curd based formulations;
- Halwa;
- Kheer;
- Other sweat meats (such as channa roll, sweet curd, laddoo, etc.);

TABLE 4.1 Types of Formulated Foods

Baby foods	Foods for infants, pureed or strained fruits and vegetables with cereals, mashed fruits in yogurt
Convenience foods	Snack packs, T.V. dinners, etc.
Dairy analogs	Formulated non dairy products, soy based products
Geriatric foods	Foods formulated for old aged people as banana split oatmeal
Low calorie foods	Diet of less than 800 kilocalories per day, for example, Tofu, dried fruits
Meat analogs	Texturized vegetable protein foods
Novelty foods	Imitation Cavier, French fried molded onion rings
Snack foods	Extruded products such as roasted chickpeas, herbed cashews, baked kale chips
Soft moist foods	Intermediate moisture foods
Special purpose dietary foods	Low cholesterol, low fat, sugar free, low sodium, etc.

- Paneer and Channa formulations;
- Using ayurvedic traditions – Ksheer pak (e.g., arjuna chhal is cooked in milk);
- Yoghurt based formulations.

This chapter discusses needs for developing fruits, vegetables and soy proteins isolates with improved flavor, color and functionality for producing formulated foods. The chapter also considers alternative technologies for incorporating fruits, vegetables and soy proteins into the formulation so that they may function properly for forming stable solutions, emulsions, foams and gels that resemble those in their natural counterparts.

4.2 PRINCIPLES OF FOOD FORMULATIONS

Formulated foods are manufactured by combining the three basic building blocks of the food (protein, fat and carbohydrate) in the way to provide best texture, flavor and other desirable characteristics. This involves manipulation of these three components along with water, vitamins, preservation, etc. to design product with predictable composition, flavor, texture and storage properties. In the design of formulated food, it is important to emphasize on solid-liquid phase equilibria, multi component solubility behavior, polymorphism, nucleation, crystal growth, wetting, emulsification, stability of disperse phase and mechanical properties of crystal assemblies.

Protein fortification in food and beverages is a key imperative to meet global challenges in nutritional deficiencies. Animal proteins typically provide complete protein, but soy is one of the best plant sources that also provide a complete protein. There has been a notable shift toward plant-derived proteins that offer similar or superior functional properties. Sensory properties are important to successful penetration of plant protein ingredients into applications dominated by animal proteins, as well as for development of new applications.

4.3 NEED FOR FORMULATION AND PROTEIN CHEMISTRY

Formulation of foods is required due to:

- Lower cost: The cost of certain formulated foods may be lower while providing about the same nutrition and satiety, for example, margarine.
- The nutritional properties of the food may be enhanced: Fruit juices fortified with Vitamin C, margaine with Vitamin A, cereals with iron and other nutrition.
- Food can be made more convenient.
- Food can be formulated to fill special needs.
- Formulated foods can fill other meal advantages. They can improve the balance of the meal.
- They can increase palatability and finally can provide satiety and other advantages.

Proteins are added to food for nutritional reasons and for their functionality. Functional abilities include viscosity enhancement and water binding, gelation, aeration and foaming and emulsification with contributions to a food's flavor, texture and color.

When formulating a food or beverage, it is advisable to first consider why a protein ingredient would be used. For example, if it is just for viscosity or emulsification, alternatives such as starch or a lipid-based emulsifier are available, because proteins are the most expensive macro-ingredient as compared to carbohydrates and fats. Beyond functionality, other factors that influence which protein is chosen for a product's formulation includes the percent of protein within the ingredient, digestibility, allergenicity, label simplicity, desired label claims, animal welfare, and amino acid profile and score. A wide range of food components can contribute proteins at a wide range of costs. Soy proteins are one of the most economical. They offer good nutritional quality and the soy industry provides soy proteins in numerous forms for specific needs.

There are a number of dairy food systems, for example, fluid milk, infant formula, coffee whitener, sweet and sour cream, margarine, cheese, frozen dessert and whipped topping, which offer opportunities for utilizing vegetable proteins in place of milk protein products [7]. Significant progress has been made in developing technologies for utilizing vegetable proteins in a number of simulated dairy food systems; however, several important problem areas must be solved before vegetable protein can be universally used in such dairy food systems. First, it will be necessary to produce "second generation" vegetable protein isolates [26] with improved flavor, color, and functionality compared to those presently available. Second, it will be necessary also to devise new and improved technologies for formulating the simulated dairy food products that will promote the vegetable protein's ability to provide the necessary functional attribute. Initially, it would be advantageous to gain a thorough understanding of the fundamental properties of the vegetable protein system which control and limit their functionality in each of the application areas. A similar degree of understanding of the basic properties of the vegetable protein system will be helpful in attempting to overcome technical problems associated with utilizing them in simulated dairy food systems. It is felt that concentrating on the basics offers more promise for solving the serious problem areas than merely attempting to develop a special protein isolate or a special technology for each particular food application.

Pea protein is non-genetically modified (GMO), is not a known allergen and contains no gluten. In agriculture, the low-water usage and nitrogen fixation properties of pulse crops makes them more sustainable than some other protein crops. Peas are low in cysteine and methionine, but high in lysine, resulting in high Protein Digestibility Corrected Amino Acid Score (PDCAAS).

Pea protein properties and applications depend on the method used for isolation, which result in different albumin, vicilin and legumin ratios. This likely explains the differences in behavior between various pea protein products on the market. Generally, pea proteins show good water binding, gelation and emulsification but lesser foaming properties.

Other types of protein that are under development or that have recently entered the market include potato, rice, canola-rapeseed (mustard), quinoa, oat, flax, hemp, algae and leaf material. To utilize low-cost proteins, the physiochemical properties need to be understood and tailored to the intended use. The development and understanding of soy protein as an ingredient for the food industry can, therefore, serve as a model for the utilization of other plant-based proteins (Figure 4.1).

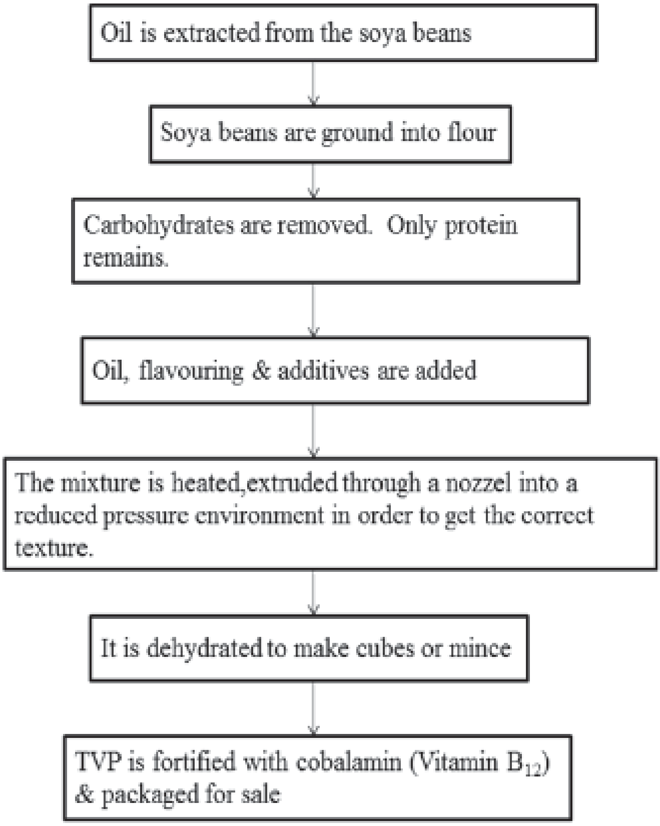

FIGURE 4.1 Flow diagram for manufacturing of texturized vegetable protein.

Meat analogs containing fibrous, vegetable proteinaceous materials (often referred to as textured vegetable proteins) are used as meat substitutes. Meat analogs may be prepared by combining the textured vegetable protein with an edible binder, fats, flavoring agents, etc. and fabricated so as to resemble natural meat cuts. Hydrated, textured vegetable proteins are also used as proteinaceous diluents or extenders in comminuted meat products.

Pliable vegetable proteins suitable for use as extenders or textured vegetable proteins in meat analogs are prepared by forming a homogeneous aqueous dispersion of water-soluble vegetable protein and edible plasticizers, drying and heat-denaturing the dispersion so as to form a mass and hydrating the mass with an aqueous acid to convert the hydrate to a pliable protein product. Flow diagram for manufacturing of texturized vegetable protein is shown in Figure 4.1. Illustrative product formulating ingredients include soy protein concentrates, polyols, triglycerides and lactic acid as an acidulant.

Nowadays, food industry is marked by the high volume of waste produced. According to the recent research conducted by FAO, about 1.3 billion tons of food is wasted worldwide per year, which represents one-third of the total food industry production [14]. The largest amount of loss is found by fruits and vegetables, representing 0.5 billion tons. In developing countries, fruit and vegetable losses are severe at the agricultural stage but are mainly explained by the processing step, which accounts for 25% of losses [14].

Fruits and vegetables are extensively processed and the residues are often discarded. However, due to their rich composition, they could be used to minimize food waste. Development of food products based on the solid residue generated from the manufacture of an isotonic beverage could be accepted (Figure 4.2). These types of beverages could be produced based on integral exploitation of several fruits and vegetables: orange, passion fruit, watermelon, lettuce, courgette, carrot, spinach, mint, taro and cucumber. The remaining residue could be processed into flour. The fruit and vegetable residue (FVR) flour could be incorporated with different levels into biscuits and cereal bars (Figure 4.2).

High fiber, protein and mineral contents and also the water holding capacity (WHC) and oxygen holding capacity (OHC) of the FVR flour

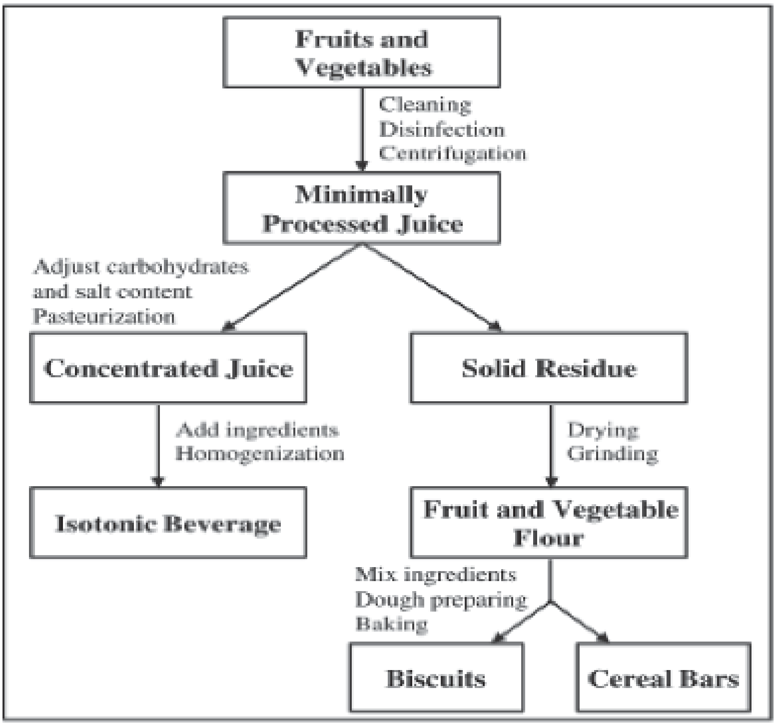

FIGURE 4.2 Flow diagram for the isotonic beverage, fruit and vegetable residue flour, biscuit and cereal bars production.

are potentially suitable for use in food applications as a new low-calorie and functional raw material. The designed products have high fiber content, reasonable consumer acceptance and were microbiologically stable. Such research promotes the reducing food waste since whole plant tissues have been used leading to the maximum exploitation of food raw materials.

4.4 PRODUCTS MADE FROM BLEND OF MILK AND COCONUT MILK

Coconut milk contains carbohydrates (mainly sucrose and some starch), lipid and minerals like P, Ca, & K. Coconut protein is rich in lysine, methionine and tryptophan [21]. Yoghurt had been made from mixtures of cow milk and coconut milk in different combinations or even from blend of coconut milk and SMP [9]. This practice would be an interesting option in high coconut producing regions and countries.

4.5 MILK SOLIDS WITH VEGETABLES

It has been reported that the reduction by 50% in risk of developing some forms of cancer through intake of 400 to 600 g of fruit and vegetable per day [15]. Broccoli is one of the richest sources of health promoting glucosinolates, antioxidants and essential nutrients viz., fiber, Ca, Mg, Se, Zn, ascorbic acid, folate, β-carotene, protein, etc. Cheese has health promoting characteristics associated with certain immune functions in the body due to bioactive peptides and conjugated linoleic acid (CLA). Cheese is rich in minerals like Ca, Mg, P and fat-soluble vitamins and possesses anti-caries function. A blend of Blue cheese powder containing up to 10.0 to 20.0% of freeze dried broccoli sprouts powder has been acceptable as a novel 'health-promoting' food. Such cheese powder had total antioxidant capacity (ascorbic acid equivalent), total polyphenols (gallic acid equivalent), total chlorophyll and total carotenoids of 53.5, 4504.2, 147.1 and 59.8 μg/g dry weight basis (DWB), respectively [22].

Carrot is rich in β-carotene (concentration of 39.6 and 23.9 mg/100 g in fresh and powdered carrot respectively), the precursor of vitamin A and contains an appreciable amount of vitamin B_1, B_2, B_6 and anthocyanin pigment. The sweetness of carrot is due to presence of sucrose, maltose and glucose. Carrot intake may enhance immune system, and protect against high blood pressure, osteoporosis, cataracts, arthritis, bronchial asthma and urinary tract infection [3]. Buffalo or cow skim milk has been blended with carrot juice (7.0% TS) and added with 8.0% sugar and 0.2% gelatin to prepare a nutritious beverage; and levels above 20.0% carrot juice incorporation resulted in sedimentation [23].

A sterilized carrot *kheer* (sweetened concentrated milk) has been developed using milk added with 8.0% sugar, dry fruit and 30.0% of shredded carrot that was previously cooked in *ghee*. The technology of preparing carrot *burfi* (*Khoa* based sweet meat) is very popular in India whose method has been standardized [18]; the product had 8.2% fat and 33.3%

TS [20]. A *kheer* mix has been formulated based on dehydrated carrot, skim milk, sugar, corn flour, cashew and cardamom [16]. A healthy bottle gourd *halwa* (similar to *burfi*) has been successfully standardized [8]. Cheese powders with additional flavor profiles such as cheese with bacon, onion or tomato, are products that would be suitable for quiches, pizzas and pasta meals [1].

4.6 MILK SOLIDS WITH FRUIT

Fruit are invariably used for flavoring of several dairy products. However, due to the presence of phytochemicals in most of the fruits, its involvement has increased looking at the 'wellnesses' of the product containing it. Fruits are rich sources of various important phytonutrients namely, vitamins, minerals, antioxidants and dietary fibers. Incorporation of fruits in milk products not only aids in 'value-addition' and 'product diversification,' but also helps in checking the post harvest losses.

Merging of dairy products and fruit beverage markets with the introduction of 'juice-ceuticals' like fruit yogurt beverages that are typical examples of hybrid dairy products offering health, flavor and convenience. Typical examples related to inclusion of fruit solids in dairy based products include ice cream and frozen desserts, stirred yogurt, fat spreads, etc.

4.7 MILK SOLIDS WITH VEGETABLE OILS: FILLED DAIRY PRODUCTS, CHEESE ANALOGUES AND FAT SPREADS

4.7.1 FILLED PRODUCTS

Filled products are the one in which milk fat is replaced completely by vegetable oils and fats. This is mainly done to have a dietetic product without cholesterol and with low levels of saturated fats. Typical examples include filled milk, filled whipped cream, filled ice cream, etc. Corn, olive, and groundnut oil were found suitable for preparing 'filled strawberry yogurt' containing 1.5% vegetable oil. The filled yogurt had higher proportion of PUFA and mono unsaturated fatty acids [2].

4.7.2 NON-DAIRY COFFEE WHITENER

The formulation for a non-dairy coffee whitener/creamer comprised of (on dry matter basis) 60.0 to 65.0% corn syrup solids and maltodextrin, 20.0 to 32.0% vegetable oil having 35 to 40°C melting point, 2.0 to 5.0% Na-caseinate, 1.0 to 3.0% disodium phosphate, 1.0 to 3.0% emulsifier, stabilizer and cream flavor [13].

4.7.3 CHEESE ANALOGUES

Analogue cheese, cheese substitute of imitation cheese are synonyms for diverse type of cheese materials that use vegetable oils instead of butter fat and contain casein or caseinates as the protein source. The protein source can also be from vegetable (soybean, groundnut) sources. The texture and flavor profile of such cheese analogs is governed by the type of oil, protein, starch, hydrocolloid and emulsifying salts used in the formulation. The vegetable oil is required to be partly hydrogenated or suitably modified in order to elevate its melting point to a level near to that of milk fat [6].

4.7.4 MIXED FAT SPREADS

A good example of mixed fat spread is ‘Bregott,’ developed and marketed by the Swedish Dairies Board. The product was made using ripened cream (35.0% fat, pH 4.6 to 4.7) to which refined soy bean oil was added (at levels of 20.0% of total fat) and after aging churned to obtain fat spread that had superior spreadability at refrigeration temperature [25]. Safflower seed based fat spread has been prepared from *chakka* (partly dehydrated *dahi*) obtained from a blend of buffalo milk and safflower milk (1:1); the additives were 1.0% tri-sodium citrate, 0.1% potassium sorbate, 1.5% common salt and 10.0% of cheese as flavoring. The low-fat spread had low cholesterol and was rich in PUFA (Polyunsaturated fatty acid) compared to product made from cow/buffalo milks; the cost and calorie was also lower for the former product [10]. Spreads with increased content of ω-3 fatty acids have been developed using olive oil [19].

4.8 PRODUCTION OF SIMULATED DAIRY FOOD SYSTEMS

Simulated dairy food products require soy or vegetable protein isolates with significantly improved flavor, color, and functional properties. The need for such high quality protein products stems from the fact that milk and most dairy food products have an extremely mild and delicate flavor, low color level and exhibit a characteristic texture that will not accommodate even a minor alteration. Even though certain fermented dairy foods and cheese products possess a highly viscous or gelled structure and have a characteristic flavor and color, soy and vegetable protein products must not detectably alter these properties or they will be readily identified as inferior products by the consumer. Figure 4.3 depicts some of the examples of the soy-based foods.

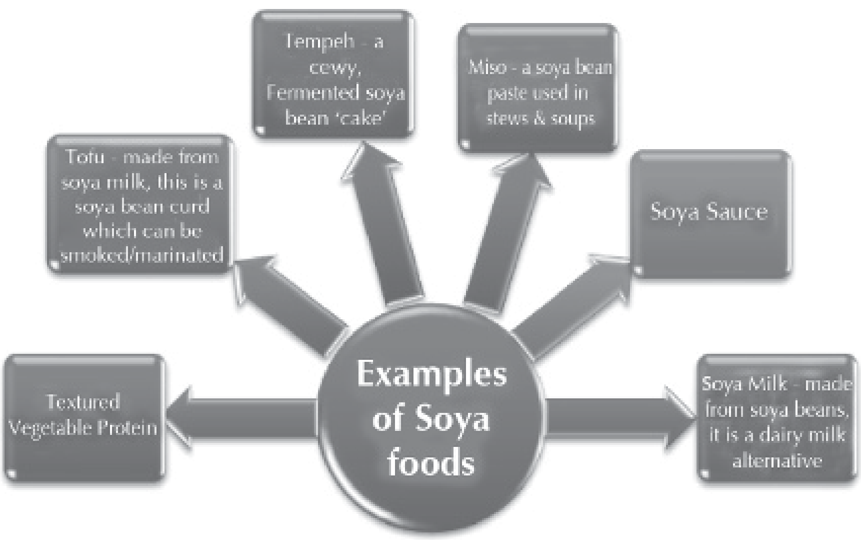

FIGURE 4.3 Examples of soy based foods.

4.9 FORMULATION OF VEGETABLE PROTEIN AND FIBER: CHALLENGES AND SOLUTIONS

Protein and fiber are added to food systems for many reasons, both functional and nutritional. However, with their addition comes the need for ingredient and processing adjustments, depending on the final food and its desired characteristics.

Strategies to overcome these issues include use of multiple sources of protein and fiber. In addition to protein powders, nuggets or crisps can be high in protein and also contain fiber. Coatings can be protein or fiber fortified. Cereal pieces, like oats, wheat flakes, nuts, pulse flour, or pieces and seeds, are other sources of protein and fiber. Protein hydrolysates are helpful to overcome such problems.

Processing technology innovations will also be needed to successfully produce simulated dairy food products using soy and vegetable proteins. Properly established procedures for solubilizing, blending and incorporating soy and vegetable proteins into the formulation, which will presumably replicate the composition and overall properties of milk or the other natural dairy food system, will be essential for successfully utilizing these proteins in simulated dairy food and other system.

4.10 CONCLUSIONS

Vegetable proteins have source of adequate protein for the formulation of new food products. It has been proved from many researches that attention should be paid to the mixture of vegetable proteins to meet the adequate nutritional quality needed for the promotion of growth of infants, adults and aged people. The results of vegetable based formulated foods expatiate in terms of nitrogen retention in various tissues of the body. Food consumption, nitrogen retention, average protein level and optimum growth rate were found to be inter-related. From the economic and health benefit point of view, newly formulated diets could be produced in a much cheaper rate than the commercial available products. Investigation of such products will be useful to industries and common people in generally to alleviate protein energy malnutrition in developing countries.

4.11 SUMMARY

At present, food processing industry is giving increased emphasis on the production and utilization of alternate protein isolate products as functional and nutritional ingredients in an expanding number of formulated food products. Alternate protein sources such as fruits, vegetables and soy proteins offer additional flexibility in formulating foods due to their economics, availability, functionality and nutritional properties.

This chapter discusses needs for developing fruits, vegetables and soy proteins isolates with improved flavor, color and functionality for producing formulated foods. It also considers alternative technologies for incorporating fruits, vegetables and soy proteins into the formulation so that they may function properly for forming stable solutions, emulsions, foams and gels that resemble those in their natural counterparts.

Properly established procedures for solubilizing, blending and incorporating fruits, vegetables and soy proteins into the formulation, which will presumably replicate the composition and overall properties of milk or the other natural food system, will be essential for successfully utilizing these proteins in simulated food products. Food manufacturers throughout the world have developed many dairy-related products that contain fruits, vegetables and soy proteins and sodium caseinate. Also, dietary, religious, and ethnic constraints have become increasingly important considerations in the formulation and market of these products.

Any food product made out of milk will obviously be highly nutritious. However, milk has certain limitations like allerginicity, lactose intolerance, cholesterol, saturated fat content, etc. With advancement in technology, several dairy derived ingredients are being produced that when used in conjunction with other food ingredients in food manufacture can yield 'value-added' products that have balanced nutrition, and exhibiting superior functionalities as well as 'wellness' in food application. This implicates the synergy of dairy with other food ingredients/products; such combination exhibits effects that are probably not obtained when either ingredient is used singly. Dairy along with fruit and vegetable ingredients may get transformed into 'formulated foods.'

Combining the neutraceutical components of dairy and non-dairy based food item, a new 'value added' product can emerge that can fulfill the ever increasing demand for 'wellness food' by the 'health conscious' consumers. With further research on dairy ingredients and their interaction with other food constituents and ingredients, more and more new 'novel' products would be developed for 'enjoyment' and 'wellness' of the consumers.

KEYWORDS

- **cholesterol**
- **conjugated linoleic acid**
- **fabricated foods**
- **formulated foods**
- **genetically modified**
- **malnutrition**
- **Maltodextrin**
- **miso**
- **mozzarella**
- **neutraceutical**
- **oxygen holding capacity**
- **phytochemicals**
- **polyunsaturated fatty acid**
- **protein digestibility corrected amino acid score**
- **protein hydrolysates**
- **tempeh**
- **texturized vegetable protein**
- **tofu**
- **value-added**
- **water holding capacity**
- **β-carotene**
- **ω-3 fatty acids**

REFERENCES

1. Anon. (1994). Powder performance. *Dairy Ind. Intl*., *59*, 42–44.
2. Barrantes, E., Tamime, A. Y., & Sword, A. (1994). Oils versus milk fat. *Dairy Ind. Intl*., *59*, 25–30.
3. Beom, J., Yong, S., & Myung, H. (1998). Antioxidant activity of vegetables and blends in iron catalyzed model system. *J. Food Sci. Nutr*., *3*, 309–314.
4. Betoret, E., Betoret, N., Vidal, D., & Fito, P. (2011). Functional foods development: Trends and technologies. *Trends Food Sci Technol*., *22*, 498–508.
5. Bhardwaj, R. L., & Pandey, S. (2011). Juice blends—a way of utilization of underutilized fruits, vegetables, and spices: a review. *Crit Rev Food Sci Nutr*., *51*, 563–570.
6. Chavan, R. S., & Jana, A. (2007). Cheese substitutes: An alternative to natural cheese: a review. *Intl. J. Food Sci. Technol. Nutr*., *2*, 25–39.
7. Circle, S. J. (1974). JAOCS 51, 198A.
8. Dalal, T. (2008). Healthy halwas – Bottle gourd halwa. In: *Mithai*. Chapter 3. Sanjay and Co. Pub., Mumbai, pp. 53–54.
9. Davide, C. L., Peralta, C. N., Sarmago, I. G., & Sarmago, L. J. (1990). Yoghurt production from a dairy blend of coconut milk and skimmed milk powder. *Philippine J. Coconut Stud*., *11*, 51–58.
10. Deshmukh, M. S., Patil, G. R., Sontakke, A. T., Kalyankar, S. D., & Padghan, P. V. (2003). Storage study of low-fat spread from safflower milk blended with buffalo milk. *J. Dairying Foods and Home Sci*., *22*, 63–66.
11. Dominguez-Perles, R., Moreno, D. A., Carvajal, M., & Garcia-Viguera, C. (2011). Composition and antioxidant capacity of a novel beverage produced with green tea and minimally-processed byproducts of broccoli. *Innov Food Sci Emerg Technol*., *12*, 361–368.
12. Ferreira, M. S. L., Santos, M. C. P., Moro, T. M. A., Basto, G. J., Andrade, R. M. S., & Gonçalves, E. C. B. A. (2015). Formulation and characterization of functional foods based on fruit and vegetable residue flour. *J Food Sci Technol*., *52*(2), 822–830.
13. Gardiner, D. S. (1977). *Non-Dairy Creamer Compositions*. United States Patent No. 4,046,926.
14. Gustavsson, J., Cederberg, C., Sonesson, U., & Van Otterdijk, R. A. M. (2011). *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Food and Agriculture Organization of the United Nations (FAO), Rome.
15. Heber, D. (2004). Vegetables, fruits and phytestrogens in the prevention of diseases. *J. Postgrad. Med*., *50*, 145–149.
16. Manjunatha, S. S., Kumar, B. L., Mohan, G., & Das, D. K. (2003). Development and evaluation of carrot kheer mix. *J. Food Sci. Technol*., *40*, 310–312.
17. Martins, R. C., Chiapetta, S. C., Paula, F. D., & Goncalves, E. C. B. A. (2011). Evaluation isotonic drink fruit and vegetables shelf life in 30 days. *Braz J Food Nutr*., *22*, 623–629.
18. Mathur, S. (2008). Carrot burfi. In: *Indian Sweets*. Ocean Book Ltd. Pub., pp. 35–36.
19. Mortensen, B. K. (2009). Production of yellow fats and spreads. In: *Dairy Fats and Related Products*, edited by Tamime, A. Y., Blackwell Pub. Ltd., pp. 167–194.
20. Qureshi, M. A., Goel, B. K., & Uprit, S. (2007). Development and standardization of sterilized carrot kheer. Egypt. *J. Dairy Sci*., *35*, 195–197.

21. Seow, C. C., & Gwee, C. N. (1997). Coconut milk: chemistry and technology. *Int. J. Food Sci. Technol.*, *32*, 189–201.
22. Sharma, K. D., Stahler, K., Smith, B., & Melton, L. (2011). Antioxidant capacity, polyphenolics and pigments of broccoli cheese powder blends. *J. Food Sci. Technol.*, *48*, 510–514.
23. Singh, C., Grewal, K. S., & Sharma, H. K. (2005). Preparation and properties of carrot flavored milk beverage. *J. Dairying Foods Home Sci.*, *24*, 184–189.
24. Sun-Waterhouse, D. (2011). The development of fruit-based functional foods targeting the health and wellness market: a review. *Int J Food Sci Technol.*, *46*, 899–920.
25. Wilbey, R. A. (1986). Production of butter and dairy-based spreads. In: *Modern Dairy Technology, Advances in Milk Processing*, edited by Robinson, R. K. Elsevier Appl. Sci. Pub., London, *1*(3), 93–129.
26. Wolf, W. J., & Cowan, J. C. (1975). *Soybeans as a Food Source*. CRC Press, Cleveland, OH.

PART II

PROCESSING METHODS AND THEIR APPLICATIONS IN THE DAIRY INDUSTRY

CHAPTER 5

APPLICATION OF SCRAPED SURFACE HEAT EXCHANGER IN MANUFACTURING OF DAIRY PRODUCTS: A REVIEW

A. V. DHOTRE and A. G. BHADANIA

CONTENTS

5.1 INTRODUCTION

For processing milk to milk products, number of unit operations are employed, namely: filtration, clarification, fractionation, chilling, freezing, preheating, homogenization, pasteurization, sterilization, concentration, drying, curing, etc. Majority of these operations involve heat transfer, which is commonly done by employing indirect type of heat exchangers, wherein the heat transfer takes place through a metallic heat transfer surface. The inherent problems associated with the use of indirect heat exchangers include fouling of heat transfer surface, low degree of turbulence over heat transfer surface on both sides due to boundary layer formation, difficulty in cleaning and sanitization, failure to handle viscous and/or particulated products.

These shortcomings are greatly mitigated in a scraped surface heat exchanger (SSHE). The scrapers in SSHE continuously scrape the product off the surface, thus eliminate fouling, increase turbulence, aid in controlling product residence time, mix the product, avoid localized treatment and also facilitate the cleaning operation. These features have greatly increased the applications of SSHE for manufacturing dairy products especially traditional dairy products (TDP) over last three decades. SSHE has also been used for the manufacture of several western dairy products [5, 30]. The SSHE has been employed for many processing milk into many dairy products majority of which are the indigenous milk products of India.

This chapter is an attempt to discuss these applications in the dairy industry.

5.2 SCRAPED SURFACE HEAT EXCHANGER

The SSHE also-called as swiped surface heat exchanger is a special type of tubular heat exchanger. In its simplest form, a SSHE consists of: (1) jacketed stationery cylinder called as product tube or barrel; (2) a rotating cylinder or shat carrying scraper blades; (3) inlet and outlet ports; and (4) accessories for sensing, controlling and safety purpose. The material to be processed flows axially through the annular section between the stationary outer cylinder and rotor. The moving blades scrape the heat transfer surface periodically to prevent the deposition of material and promote mixing [28].

The mechanical action of scraper blades on the heating surface enhances heat transfer, prevents fouling and to some extent regulates the residence time distribution. Extensive information has been presented [5, 30] on flow patterns, mixing effects, residence time distribution, heat transfer, power requirements of SSHE and their applications in food processing. The inherent features of SSHE make it suitable to handle the products with high viscosity and particulate structure, which occurs in most of the dairy product especially in traditional Indian dairy products (TIDP). Moreover, the operating parameters (such as residence time, temperature, pressure, speed of rotation, etc.) can be easily controlled as compared to the kettle method. Therefore, the SSHEs have replaced many kettle based units that were used in the manufacture of dairy products [7]. The numerous applications of SSHEs are discussed product wise in this chapter.

5.3 MILK CONCENTRATION FOR MAKING KHOA AND ALLIED PRODUCTS

Khoa is the product obtained by partial desiccation or dehydration through boiling of whole milk under atmospheric conditions. Requirement of constant stirring and scraping while heating is the specific feature of the khoa making process [29]. The concentration of milk solids is almost increased by 5 times during the manufacture of khoa.

In order to overcome the drawbacks of traditional method of khoa making, such as limited capacity, lot of time and labor requirement and necessity to clean pan between batches, Banerjee, et al. [8] designed and developed equipment for continuous khoa making (Figure 5.1). It consists of a steam jacketed drum heater, open steam jacketed pans and power driven scrapers. In this equipment, milk at the rate of 50 liter per hour is gradually concentrated by heating it in a steam jacketed drum heater operated at 3 kg/cm^2 (294.3 kPa) steam pressure followed by further heating and concentrating it in open steam jacketed pans. Since the unit was made of mild steel, the product was prone to oxidation and discoloration [49], the plant did not work effectively owing to the lack of controls for regulated supply of milk [14]. Therefore, the method for production of khoa with this machine was specially standardized [18] with suggestion to improve some constructional features of the machine. The improvements were incorporated and new design was fabricated using stainless steel [35, 47], which performed satisfactorily on small and medium scale production. A khoa making equipment consisting of a hemispherical open pan weld mounted on a cylindrical water jacket has also been reported for village level operations [6].

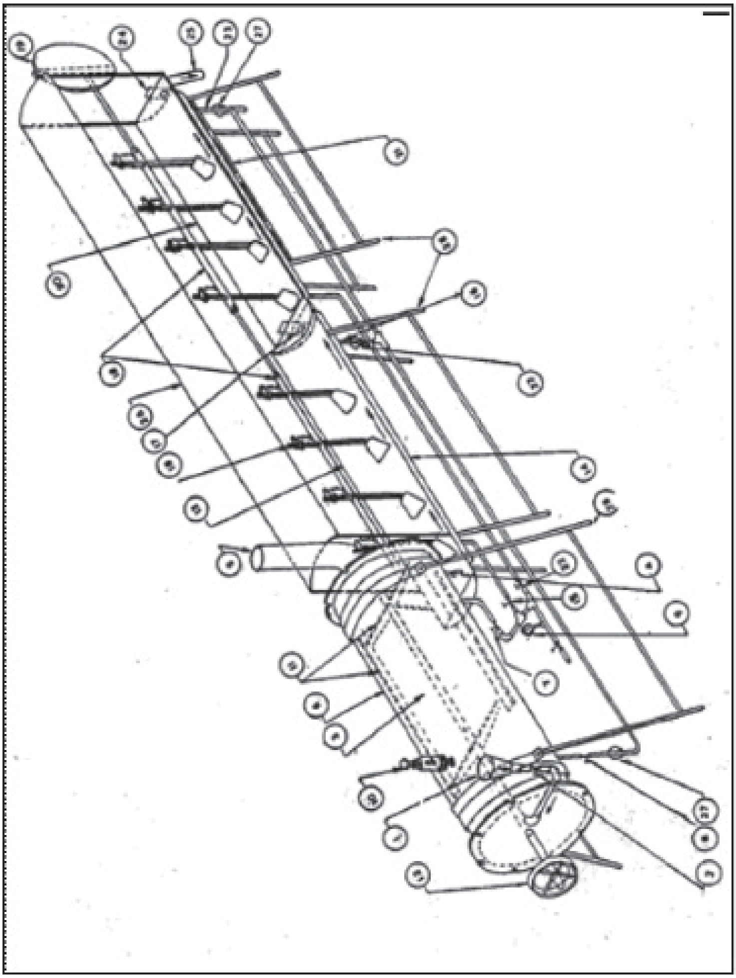

FIGURE 5.1 Continuous khoa making machine [8].

Alfa Laval has introduced Convap: an adaptation of the basic Contherm unit that allows the unit to operate as a SSHE evaporator [7]. Contherm heat exchanger can easily be converted into Convap by adding a vapor dome, instead of a top head assembly and with the addition of auxiliaries like vapor separator, condenser and a vacuum pump. It has been adopted at Chitle farm, Pune for khoa making [22].

Aiming for better thermal efficiency, a Conical Process Vat working on SSHE principle has been developed at NDRI, Karnal. It consists of a steam jacketed conical vat with cone angle of 60°. The jacket is partitioned into four segments to provide variable heating area for efficient use of thermal energy. The rotary scrapers were designed to offer a uniform centrifugal force of scraping at all points on heat transfer surfaces. The scraping assembly is coupled to a variable speed drive to control rpm at different stages of khoa preparation. There is provision for recirculation of the milk during concentration so that the heat transfer area of the cone can be reduced to get better thermal performance [22], with decrease in the bulk. Sometimes due to recirculation, quality of the product deceases during conversion to khoa. However, it has been successfully used for preparation of basundi [48] and has been integrated with SSHE for preparation of rabri [15].

A SSHE based batch equipment for hygienic manufacture of khoa was also developed [36] consisting of a stationary-jacketed drum with steam inlet, condensate outlet through steam trap and pressure gage. Power operated spring loaded scraper enhanced heat transfer and mixing of the product. The steam temperature of 121°C and scraper speed of 28 rpm were reported as optimum operating parameters. A prototype khoa making machine based on horizontal SSHE was developed using mild steel and subsequently modified using stainless steel [16] with feed capacity of 50 kg of milk per hour per batch. The unit consists of a steam jacket divided into three compartments for better control of heating process as the content reduces during later part of khoa making. The scraper blades are spring loaded on the assembly, which is arranged in such a way that the whole surface is efficiently scraped [22]. The perforations on upper side of drum facilitate milk feeding, exhaust of vapor and supervision of concentration process. The steam jacket can be fed with cold water for cooling the finished product. Upon evaluation for the batch-wise production of khoa and allied products, the machine was found suitable for preparing 32 kg of carrot-milk halwa in 2.5 h, 30 kg of bottle guard halwa in 3 h, 35 kg of rice-milk kheer in 45 minutes, 25.5 kg of basundi in 1 h and 18 kg tomato ketchup in 2 h by making relevant changes in the operating variables of the machine [51]. However, for production of large quantities for industrial operation, the need of continuous khoa producing unit was felt. The National Dairy Development Board at Anand [43] has developed continuous khoa making machine using liquid full type Inclined Scraped Surface Heat Exchanger (ISSHE). In this machine, the milk is fed by positive displacement pump at the lower end of inner cylinder of ISSHE, where it forms a pool of boiling milk. The jacket has three – compartments. The rotor is screw shaped with scraper blades fitted in a staggering manner. Thus, while rotating the scraper, blades perform the basic function and the screw like portion conveys the milk towards the upper end of ISSHE. The milk flows back to the pool and the concentrated milk (solid mass conveyed to the top) is discharged as khoa. The limitation with the machine was that it requires pre-concentrated milk to around 45% TS [23].

Beside liquid full SSHE, the thin film SSHE was also applied in milk dairy operations [3]. A continuous khoa making unit, operating on the principle of thin film scraped surface heat exchanger (TFSSHE) [27], produced acceptable quality khoa when the equipment was operated under standardized conditions. But higher rotor speed had adverse effect on flavor and texture of khoa. Therefore, two TFSSHEs were used in cascade manner. First SSHE has four adjustable clearance scraper blades rotating at 3.3 rps and second SSHE has two adjustable clearance scraper blades and two helical blades to push the product forward, rotating at 2.5 rps. Performance of this system was tested on large scale and was found satisfactory; and khoa prepared was better than that prepared with batch-wise operation. The unit was further modified as continuous burfi making machine by adding a third stage [33] and its performance was evaluated for burfi making [22].

During conversion of milk to khoa, its TS concentration increases to 60–67%, for example, almost 5 times, radically changing its physico-chemical properties. Therefore a single unit converting milk to khoa cannot be compatible at all stages throughout the concentration process and that also with engineering parameter as well as technological and quality aspects. One set of design parameters, which is efficient during initial stages of concentration, will fail in the final stage and vice versa. Similarly, the unit operating at higher efficiency may give technologically inferior product and vice versa. Taking this into consideration, Christie and Shah [17] designed and developed a three-stage unit for continuous manufacture of khoa at GAU, Anand (Now, AAU-Anand). As shown in Figure 5.2, the machine comprised of three jacketed cylinders placed in a cascade arrangement with some slope to facilitate easy drainage. Each of the three SSHEs was designed according to the requirement of heat transfer area,

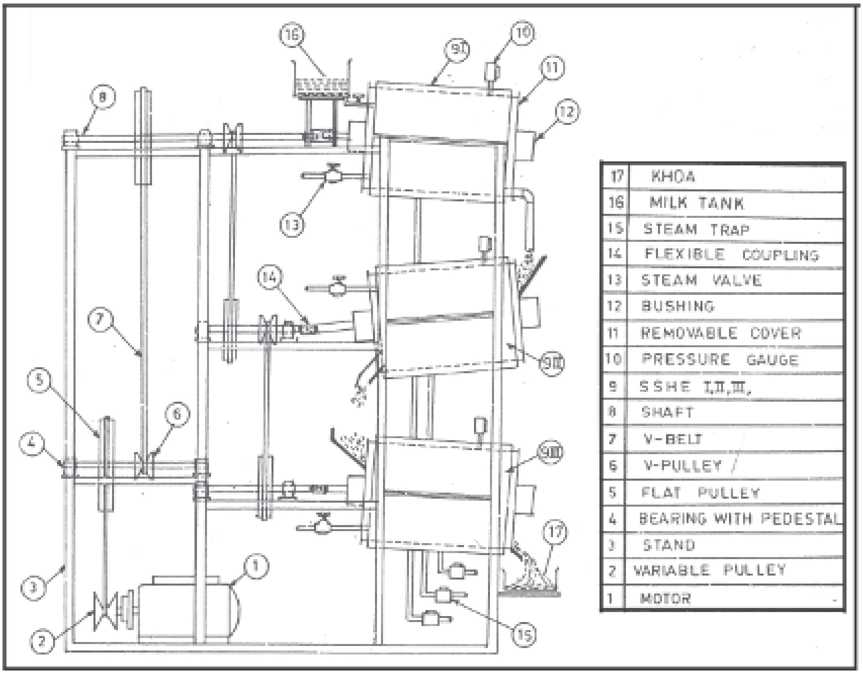

FIGURE 5.2 Continuous khoa making machine with three SSHEs [17].

temperature gradients and scraping speeds with respect to the TS concentration of milk at that particular stage. The design was further improved and tested for its heat transfer behavior [10–13].

As subsequent work for industrial application, a three stage continuous khoa making machine has been developed at NDRI, Karnal [23]. The machine in Figure 5.3 consists of three SSHE of identical length, diameter and effective heating length. All three SSHEs are provided with vapor outlets, spring loaded safety valves on jackets and glass wool insulations. The rotor assembly of first two stages consists of four variable clearance blades with spring support while that of third has only two of such blades and remaining two are skewed blades. The third stage is also provided with sugar dosing device consisting of hopper and VFD driven auger. The milk is fed geometrically to the top most SSHE by a progressive cavity pump. Concentrate from first to second and second to third flows down under gravity. A magnetic flow meter is provided in the feed line to the

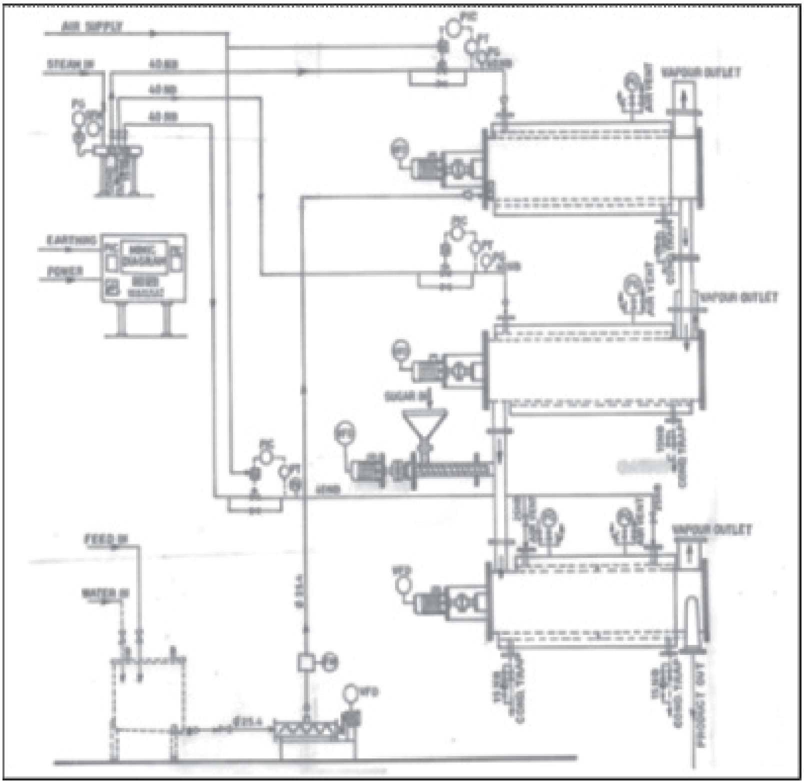

FIGURE 5.3 Modified khoa making machine [23].

first stage. The steam supply to each jacket is regulated by electrically controlled pneumatic valves. Under industrial trials, the machine has been reported to produce 50 kg/h of khoa when fed with raw milk and 120 kg/h of khoa when fed with concentrated milk (30% TS).

The successful (traditional) method of khoa manufacture clearly demarcates two unit operations. First is the fast evaporation to concentrate the milk to 45% TS by intensive heat transfer to have a desirable flavor and second is the slow heating and vigorous scraping to achieve final concentration and desirable textural attributes. The concentration with flavor development can be achieved in SSHE whereas the texture development can be accomplished in the Conical Process Vat [34]. For designing a specialized heat exchanger, it is essential to know the parameters governing heat transfer in the particular process. Following correlation can be used to calculate overall heat transfer coefficient during evaporation of milk up to 45% TS:

$$U_0 = 620.22E - 32.3S + 585.6V_c + 133.3B - 11.7 - 0.23E^2 + 0.48S^2 \\ -73.6V_c^{\,2} - 6.3B^2 - 0.17T^2 - 0.25ES + 0.64EV_c - 0.03EB + 0.71Et \\ +2.24SV_c + 0.76SB - 0.21ST - 12.0V_cB - 0.46V_cT - 0.302BT \tag{1}$$

where, S is TS in milk, Vc is the circumferential velocity, E is percent vapor fraction, B is the number of solids and T is the temperature difference.

The scraped film heat transfer coefficient during evaporation of milk to high concentration can be predicted by the following correlation [27].

$$N_u = \left[6615.1\left(N_{re}\right)_G\right]\left[0.133\left(P_r\right)_G^{0.08}\right](\Delta T / T_S)^{0.28} \tag{2}$$

where, $(Nre)_G$ is generalized Nusselt number, $(Pr)_G$ is the generalized Prandtl number, ΔT is the temperature difference, and Ts is steam temperature.

5.3.1 BASUNDI

Basundi is a traditional sweetened concentrated milk but it is characterized by its peculiar body texture consisting of very minute flakes and cooked flavor. Most of the SSHE based units developed for manufacture of khoa have been studied for the preparation of basundi and some were found satisfactory. The exclusive attempt to mechanize basundi making was made at AAU – Anand. Three pilot models (viz. cylindrical type, conical type, and Karahi type) were developed for Basundi making on the principle of SSHE (SSHE). All the models were tested for their heat transfer behavior under different operating conditions. Heat transfer and energy consumption were estimated for design optimization [46]. The heat utilization in these heat exchangers was evaluated with and without induced draft on milk surface [40]. Mechanization of manufacture of Basundi was tried using batch type stainless steel version of SSHE developed at SMC College of Dairy Science, Anand Agricultural University, Anand. The process parameters are optimized for and the product was compared favorably with products made by conventional method in the sensory and rheological profile, with better score and color.

Manufacture of Basundi was tried at NDRI, Karnal, using conical process vat and two-stage thin film SSHE with standardized buffalo milk. Basundi prepared in conical process vat, was good in body, texture, appearance and overall acceptability for processing time between 80 to 100 min [21, 48].

A Continuous Basundi Making Machine (CBM) has been developed at SMC College of Dairy Science – AAU-Anand, based on the principle of Scrap Surface Heat Exchanger (SSHE). It consists of concentration unit of three SSHEs and chilling units of two SSHEs with specially designed scrapers, variable frequency drive (VFD) to facilitate variation of speed of scrapers, resistance temperature detector (RTD) sensors and other controls to optimize processing parameters, which resulted into better quality product in terms of sensory and rheological attributes [40]. There is a forced draft-cooling tower to condense the vapors.

5.3.2 UHT PROCESSING OF MILK

The UHT processing includes heating the milk at 121°C for 2 sec or other suitable time temperature combination. The temperature, being more than the normal boiling point of milk, requires heating under high pressure to avoid evaporation and concentration. A cascaded three thin film SSHEs unit employing high pressure pump was developed for UHT processing of milk [26]. Each SSHE cylinder was made air-tight, the provision for heat regeneration and cooling required were also satisfactorily achieved in the three SSHEs.

Based on the design of contherm SSHE, Tetra Pack developed a continuous aseptic processing module (Tetratherm) for indirect UHT treatment. But that design was more suitable for tomato products, soups, sauces, desserts and viscous products even with particles than milk.

5.4 MECHANIZATION OF GHEE MAKING

Several alterations in the basic design of SSHE have been tried in order to exploit the SSHE in dairy processing. The SSHE with vertically placed product tube have been used where the vapor removal is either not required or not required essentially in the product tube itself. Ghee, the most valuable indigenous milk product, contains more than 99.5% fat and less than 0.5% moisture.

The first prototype of continuous ghee making equipment consisted of two SSHEs and two vapor separators [44]. The butter is first molten in jacketed vat and is passed to first SSHE, where it is heated to 112°C. The superheated liquid is then flashed in the vapor separator removing water. The concentrated liquid is passed to second SSHE, where it is heated to 115°C and flashed in the second vapor separator to get the final product, ghee. Due to use of SSHE, the high overall heat transfer coefficient is obtained and the temperatures 112°C and 115°C, which are essential to develop typical ghee flavor, can be quickly achieved. The operating pressure in both the SSHE is above atmosphere. Therefore, the moisture removal is possible on the principle of flash evaporation. The plant has a reported capacity of 100 kg/h.

Another continuous ghee-making plant was designed with two vertical falling film SSHE [1]. The machine is characterized by high heat transfer coefficients and better control over the quality of product, but there was no significant saving in steam consumption.

A study was undertaken to prepare ghee from cream and butter by using a vertical SSHE (120 mm diameter) having two scraper blades. Different flow rates ranging from 48 kg/h to 90 kg/h and scraper speeds from 200 rpm to 500 rpm were studied and it was found that ghee of acceptable quality could be prepared with an energy consumption of 99–187 kCal/kg of butter with that set up against the jacketed kettle, which consumed 293 kCal/kg. The film heat transfer coefficient was found to be directly correlated with the speed of the scraper and independent of the product flow rate [32].

When ghee is made from butter, the butter is first melted and the water content in it, which generally accounts for 16%, needs to be removed. It is accomplished using stratification followed by evaporation or the evaporation alone. A continuous ghee making system of capacity 500 kg of ghee per hour from butter was developed. The butter was melted employing a continuous butter melting unit and final water evaporation with a horizontal SSHE. The unit consumed 35 kg/h of steam against that of 68 kg/h required in jacketed ghee kettle of the same capacity [2, 4]. The ghee prepared in the unit was also reported to possess better shelf life [9]. The Panchmahal Dairy at Godhra (Gujarat) has also developed an industrial method for ghee making with an aim to reduce fat and SNF losses by inclusion of a serum separator and sipro-heater. The method may employ the SSHE [40].

5.5 MECHANIZATION OF MANUFACTURING OF SANDESH

Sandesh is a popular begali sweet made from chhana, a heat-acid coagulation product of milk. The process of making sandesh involves making channa from preferably cow milk, mixing sugar @ 30–35%, kneading vigorously and cooking at 70–75°C for 10 minutes. The prototype equipment for the manufacture of chhana with a capacity of 40 kg/h has been developed at National Dairy Research Institute – Karnal [45] and at Indian Institute of Technology (IIT) – Kharagpur [40]. The IIT Kharagpur demonstrated the production of sandesh in a continuous manner. Screw extruder is modified into a vented type extruder to release the vapors formed during intense heating [6].

A pilot scale SSHE has been designed and developed at AAU-Anand to mechanize sandesh making process. The SSHE works on the principle of votator type scraper assembly having four spring loaded scrapers and half round jacket. The other half of the cylinder was left unjacketed and was made perforated for the escape of vapors that generate during the process of making sandesh from chhana [37, 38]. During the batchwise manufacture of sandesh using the machine under optimum operating conditions, the U-values ranged from 131 to 639 W/m^{2}K, the outer convective heat transfer coefficient, *ho* of 12890 W/m^{2}K and the inner convective heat transfer coefficient, *hi* of 442.32 W/m^{2}K. The sensory attributes of such produced sandesh were at par with that prepared by the traditional method.

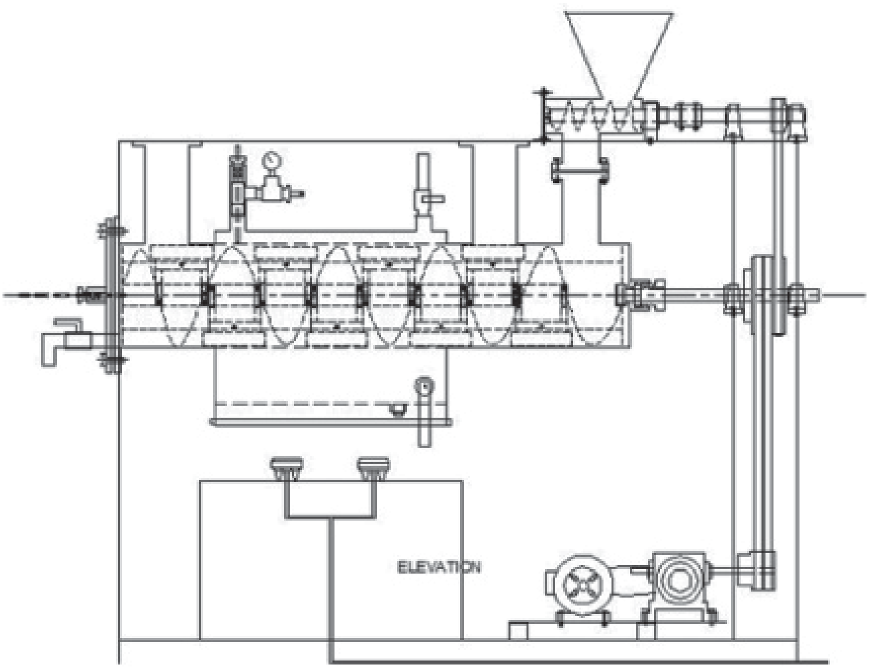

FIGURE 5.4 Continuous shrikhand thermization machine.

5.6 SHRIKHAND THERMIZATION

Shrikhand is a cultured milk product made by partially dewheying curd and blending it with sugar and/or other additives like salts, flavorings, color, fruit pulp, spices. It is popular throughout India as well as in Sri Lanka, Nepal and Pakistan. As recommended by the FSSA, shrikhand should contain minimum of 58% solids and upto 72.5% sugar (dry basis). Shrikhand contains plethora of desirable and undesirable microorganisms that bring out various biochemical changes during storage putting the safety of the stored product in question. Therefore, in spite of so high sugar and less moisture content, shrikhand is stored below 0°C and cold chain needs to be maintained from production to consumption. A post-production heat treatment known as thermization has been recommended for enhancing the shelf life of shrikhand [39, 42]. The Sugam dairy at Baroda have adopted thermization of shrikhand in a steam jacketed vat.

Suitably designed equipment for thermization of the Shrikhand is essential to achieve desirable attributes in the product. Considering the viscous nature of shrikhand, a SSHE based *Continuous Shrikhand Thermization Machine* has been designed and developed [20]. The machine in Figure 5.4 has a jacketed product tube, specially designed spring loaded scraper assembly, feeder assembly, VFD for regulating scraper speed and sensors to monitor the operating parameters of the machine. The machine uses LPG as source of thermal energy to produce steam in the jacket. While thermizing shrikhand at 70°C, 75°C and 80°C, at different scraper speeds of 20 rpm, 35 rpm and 50 rpm, an acceptable quality product was obtained. The values of overall heat transfer coefficient (U) ranged from 267.77 to 487.67 W/m^2K and the optimum capacity was 160.71 kg/h to 124.07 kg/h depending upon the TS content of chakka used for Shrikhand making. The product thermized in the machine was reported to have better sensory attributes and shelf life under refrigerated as well as ambient storage [19].

5.7 MISCELLANEOUS APPLICATIONS

A batch type Halwasan Making Machine (BHM) has also been reported by AAU – Anand. The machine works on the principle of scrape surface kettle and Halwasan prepared by using BHM is very good in quality and rheological attributes, the keeping quality of the product is reported to be 22 days at room temperature compared to the keeping quality of 8–10 days of the Halwasan made by conventional method [40].

An integrated plant for mechanized production of TIDP has been reported [40] with a milk handling capacity of 250 kg/h. The plant consists of three basic units: plate heat exchanger (PHE), twin cylinder film scraped surface heat exchanger (Twin SSHE) and Batch type Steam Jacketed Kettle. This integrated plant is suitable for mechanized value added Products like Basundi, Kheer, Peda, Thabdi, Burfi, Gajar Halwa, Halwasan, etc.

Gerstenberg Schroder, an equipment manufacturing company in Germany has developed an SSHE named as Consister, for thermal processing with simultaneous mixing of viscous fermented products. It includes a vertical product tube within which the scarper assembly rotates. The drive to the assembly has been located at bottom. The speed of the product is higher than the rotational speed achieved by the product in product tube, therefore the relative motion between the product and scraper assembly facilitate mixing. It has been used for the thermization of quark (200 kg/h, 70–72°C for 30–40 sec), a western fermented milk product resembling *Shrikhand*. Besides this, the SSHE has proven its applicability in cooling molasses, concentration of whey solids, aseptic processing of fruits for yogurt and ice cream, concentration of juices that tend to crystalize and, etc.

5.8 CONCLUSIONS

Efficient heating or cooling of complex fluids is an important requirement for several operations in dairy and food industry. SSHE is more suitable for heat transfer to viscous and heat sensitive products. It is easier to control time, temperature, speed and pressure in SSHE as compared to other type of heat exchangers. This makes it possible to achieve more even and improved quality of products. Manufacture of various dairy and food products using scraped surface processing plant increases their shelf-life. Flow patterns, mixing effects, residence time distribution, heat transfer and power requirements are major parameters for design and performance evaluation of SSHE. The choice and design of heat exchanger depends on a large number of factors such as flow rate of both streams, heat sensitivity and corrosivity of the fluids, terminal temperatures, properties of both streams, operating pressure, allowable pressure drop, fouling tendencies, inspection-cleaning and extension possibilities, type and phase of fluids, material of construction, heat recovery, flow arrangement and cost of heat exchanger. These heat exchangers can be classified according to transfer processes, degree of heat transfer, surface compactness, construction features, flow arrangements, number of fluids and heat transfer mechanism, scraper arrangement, blade clearance, design of product tube, etc. The scraping action of the blades rotating within the heat transfer tube continuously removes the product film from the heat exchanger surface and prevents burning-on, scaling or crystal build up on the wall. During operation, the product is brought in contact with a heat transfer surface that is rapidly and continuously scraped there by exposing the surface to the passage of untreated product.

The major advantages of SSHE include short residence time in heated zone so heat sensitive product can be conveniently processed, high heat transfer coefficient, narrow residence time distribution, wide viscosity range, minimum surface fouling, liquids with foaming tendency can be easily handled, low product inventory, waste heat recovery is possible for energy conservation, efficient use of thermal energy, better process control and optimization. SSHE basically consists of a cylindrical rotating shaft (the "rotor") within a concentric hollow stationary cylinder (the "stator") so as to form an annular region along which the process fluid is pumped. For maximum efficiency the product tube is manufactured from a material with a high heat-transfer coefficient. The blades are usually made from stainless steel as well as Teflon material depending on the application. Two or four blades located around the rotor throughout the product tube, though sometimes they are axially staggered in order to improve mixing. The rotating scraper helps in improving efficiency, proper mixing and imparting desirable consistency and texture to the product. The scraper may be grouped into fixed clearance scraper and variable clearance scraper. The product velocity at the heat transfer surface depends on the speed of the scraper and the effective number of the rows of the blades and does not depend on the product flow rate. Liquid-full operation and thin-film operations are commonly used in SSHE.

The overall heat transfer coefficient (U) represents the intensity of heat transfer from one fluid to another through a wall separating them. The U-value is dependent on steam side film heat transfer coefficient (h_o), product side film heat transfer coefficient (h_i) and wall heat transfer coefficient (h_w). The value of h_w is constant as it is fixed with the design of the SSHE. Heat and mass transfer equations are used in order to calculate the U-values of SSHEs. The U value is a function of blade rotational speed and mass flow rate, number of blades, temperature, feed rate, steam pressure, etc. The product side film heat transfer coefficient depends on various operating conditions of the SSHE such as scraper speed, concentration of the milk, design of the scraper, etc.

All the metallic parts that come in contact with the product should be made of SS and the nonmetallic parts coming in contact with product should be nontoxic, non-corrosive to product as well as cleaning solutions. More advanced designs of SSHE include features such as holes in the blades (which reduce power consumption), oval stators (which reduce "channeling" in which fluid passes through the exchanger relatively unprocessed), and non-centrally mounted shafts (which enhance mixing and prevent material from building up on the underside of the blades). Forward and backward tapering and Step arrangement of SSHE cylinder is also an advance design of SSHE. Rotating disc or cone type (Screw type) with advanced instrumentation plays an important role in process control and automation.

5.9 SUMMARY

By virtue of its distinguishing features such as fouling prevention, no localized heating/cooling, high heat transfer coefficient, better control on product movement, etc., the SSHEs have proven most suitable to handle viscous and/or particulate products. The operating parameters such as residence time, temperature, pressure, speed of rotation can be easily controlled in SSHE. Consequently, it has been applied widely to mechanize the production of dairy products especially the traditional Indian dairy products. Majority of Indian dairy products, which are prepared by concentrating milk leading to semi solid viscous mass have been manufactured using SSHEs. Preparation of good quality khoa and its derived products like peda, burfi, halwa and its variants are well known applications of SSHE. Apart from the milk concentration process, the SSHE have been applied in sensible heating/cooling treatments including UHT processing of milk and Thermization of Shrikhand. There is still ample scope for other applications of SSHE in manufacture of other dairy products too with some thoughtful alterations in the basic design of SSHE.

KEYWORDS

- **basundi**
- **burfi**
- **CPV**
- **ghee**
- **halwa**
- **halwasan**
- **khoa making**
- **mechanization**

- **peda**
- **sandesh**
- **shrikhand**
- **SSHE**
- **thermization**

REFERENCES

1. Abichandani, H., Agrawala, S. P., Verma, R. D., & Bector, B. S. (1978). Advances in continuous ghee-making technique, *Indian Dairyman, 30*(11), 769–771.
2. Abichandani, H., Bector, B. S., & Sarma, S. C. (1995). Continuous ghee making system – design, operation and performance, *Indian Journal of Dairy Science, 48*(11), 646–650.
3. Abichandani, H., Dodeja, A. K., & Sarma, S. C. (1989). Applications of thin film scraped surface heat exchangers, *Indian Dairyman, 41*(1), 21–24.
4. Abichandani, H., Dodeja, A. K., & Sarma, S. C. (1996). A unique system for continuous manufacture of ghee and khoa, *Indian Dairyman, 48*(10), 11–12.
5. Abichandani, H., Sarma, S. C., & Heldman, D. R. (1987). Hydrodynamics and heat transfer in thin film SSHE: A Review. *Journal of Food Process Engineering, USA, 9*(2), 143–172.
6. Agrawal, S. P. (2003). Development of equipment for manufacture of Indian milk products and future strategies. *Indian Dairyman, 55*(8), 33–37.
7. Alam, A. A. (1988). Process equipment manufacture. *Indian Dairyman, 40*, 285–290.
8. Banerjee, A. K., Verma, I. S., & Bagchi, B. (1968). Pilot plant for continuous manufacture of khoa. *Indian Dairyman, 20*, 81–84.
9. Bector, B. S., Abichandani, H., & Sarma, S. C. (1996). Shelf life of ghee manufactured in continuous ghee making system. *Indian Journal of Dairy Science, 49*(6), 398–405.
10. Bhadania, A. G., Patel, S., Shah, B. P., & Shah, U. S. (2004a). Determination of film heat transfer coefficients of Scraped Surface Heat Exchanger during manufacture of Khoa. *Indian Food Industry, 23*(3), 44–47.
11. Bhadania, A. G., Patel, S. M., Shah, B. P., & Shah, U. S. (2004b). Effect of steam pressure on overall heat transfer of surface heat exchanger during manufacture of Khoa. *Beverage and Food World, 3*, 33–35.
12. Bhadania, A. G., Shah, B. P., & Shah, U. S. (2004c). Effect of heat transfer on physico chemical and sensory quality of khoa manufactured using Scraped Surface Heat Exchanger. *Journal of Food Science and Technology, 41*(6), 656–660.
13. Bhadania, A. G., Shah, B. P., & Shah, U. S. (2005). Energy requirement of Scraped Surface Heat Exchanger (SSHE) during manufacture of Khoa. *Indian Food Industry, 86*, 13–17.

14. Boghra, V. R., & Rajorhia, G. S. (1982). Utilization of pre concentrated and dried milk for khoa making. *Asian Journal of Dairy Science, 1*, 6.
15. Chopde, S., B. Kumar, P. S. Minz, & P. Sawale (2013). Feasibility study for mechanized production of rabri. *Asian Journal of Dairy & Food Research, 32*(1), 30–34.
16. Christie, I. S., & Shah, U. S. (1990) development of khoa making machine. *Indian Dairyman, 42*, 249–252.
17. Christie, I. S., & Shah, U. S. (1992). Development of a three stage continuous khoa making machine. *Indian Dairyman, 44*(1), 1–4.
18. De, S., & Singh, B. P. (1970). Continuous production of khoa. *Indian Dairyman, 22*, 294.
19. Dhotre, A. V., Bhadania, A. G., & Shah, B. P. (2009). Effect of mechanized thermization on quality of shrikhand. *International Journal of Food Science, Technology & Nutrition*, *3*(1–2), 11–23.
20. Dhotre, A. V. (2006). Development and performance evaluation of scraped surface heat exchanger for continuous thermization of shrikhand. MSc Thesis submitted to Anand Agricultural University, Anand.
21. Dodeja, A. K., & Abichandani, H. (2004). Development of unique system for continuous production of ghee and khoa. *Beverage and Food World, 31*(8), 37–38.
22. Dodeja, A. K., & Agrawala, S. P. (2005). Mechanization for large scale production of indigenous milk products: a review. *Indian Journal of Animal Sciences, 75*(9), 1118–1125.
23. Dodeja, A. K., & N. Kishor (2011). Continuous khoa making machine – Operational features and performance of new version. *Indian J of Dairy Science, 64*(4), 283–289.
24. Dodeja, A. K., Abichandani, H., Sarma, S. C., Dharam Pal, & Pal, D. (1992). Continuous khoa making system-design, operation and performance. *Indian Journal of Dairy Science*, *45*(12), 671–674.
25. Dodeja, A. K., Sarma, S. C., & Abhichandani, H. (1989a). Thin film scraped surface heat exchanger and plate heat exchanger – A comparative study. *Indian Journal of Dairy Science, 42*, 757.
26. Dodeja, A. K., Sarma, S. C., & Abichandani, H. (1989b). Development of thin film scraped surface heat exchanger for uht processing of milk. *Indian Journal of Dairy Science, 42*(4), 760–764.
27. Dodeja, A. K., Sarma, S. C., & Abichandani, H. (1990). Heat transfer during evaporation of milk to high solids in thin film scraped surface heat exchanger. *Journal of Food Process Engineering, 12*(3), 211–225.
28. Gandhi, N., & Parikh, P. (2015). Thermal analysis of scraped surface heat exchanger used in food industries. *International J Innovative Science, Engineering & Technology, 2*(5), 622–627.
29. Gupta, S. K., Agrawala, S. P., Patel, A. A., & Sawhney, I. K. (1987). Development of equipments for indigenous dairy products, *Indian Dairyman, 39*(9), 419–425.
30. Harrod, M. (1986). Scraped surface heat exchangers: a review. *Journal of Food Process Engineering, 9*, 1–62.
31. Kohli, R. K., & Sarma, S. C. (1983). Application of scraped surface heat exchanger for making ghee. *Transactions of the ASAE American Society of Agricultural Engineers*, *26*(4), 1271–1274.
32. Kohli, R. K., & Sarma, S. C. (1990). Mechanization in ghee. *Indian Journal of Dairy Science, 43*(2), 181–184.

33. Kumar, B. K., & Dodeja, A. K. (2003). Development of continuous burfi making machine. *Indian Journal of Dairy Science, 56*(5), 274–277.
34. Mahesh, K., B. Kumar, & P. S. Minz (2012). Optimization of process parameters for manufacture of khoa using Response Surface Methodology. *Indian Journal of Dairy Science, 65*(2), 107–114.
35. More, G. R. (1983). Development of khoa making equipment. *Indian Dairyman, 35*, 275.
36. More, G. R. (1987). Development of semi-mechanized khoa making equipment. *Indian Journal of Dairy Science, 40*, 246.
37. Patel, J. S., & Bhadania, A. G. (2005a). Applications of SSHE in mechanization of Sandesh making process. *Beverage & Food World,* 46–50.
38. Patel, J. S., & Bhadania, A. G. (2005b). Heat transfer behavior of scraped surface heat exchanger during manufacturing sandesh. *Processed Food Industry*, 21–26.
39. Patel, R. S., & Abd-El-Salam (1986). Shrikhand – an Indian analog of Western quarg. *Cultured Dairy Products Journal, 21*(1), 6–7.
40. Patel, S. (2013). Mechanized manufacture of traditional milk products. Proceedings of National Seminar on Mechanized Production of Indian Dairy Products held at AAU-Anand, Gujarat during 2–3 Sept, pp. 44–51.
41. Patel, S. M. (1990). Study on heat transfer performance of SSHE during Khoa making, MSc Thesis, Gujarat Agricultural University, S. K. Nagar.
42. Prajapati, J. P, Upadhyay, K. G., & Desai, H. K. (1993). Quality appraisal of heated shrikhand stored at refrigerated temperature. *Cultured Dairy Products Journal, 28*(2), 14–17.
43. Punjarath, J. S., Veeranjaneyulu, B., Mathunni, M. S., Samal, S. K., & Aneja, R. P. (1990). Inclined SSHE for continuous khoa making. *Indian Journal of Dairy Science, 43*(2), 225–230.
44. Punjrath, J. S. (1974). New development in ghee making. *Indian Dairyman, 26*, 275–287.
45. Punjrath, J. S. (1991). Indigenous milk products of India: The related research and technological requirements in process equipment, *Indian dairyman, 43*(2), 75–87.
46. Rajasekhar, T., Shah, B. P., Bhadania, A. G., & Prajapati, P. S. (2001). Application of scraped surface heat exchangers in dairy and food industry: A Review. *Indian Journal of Dairy & Biosciences, 12*, 8–12.
47. Rajorhia, G. S., & Srinivasan, M. R. (1975). *Annual Report*. National Dairy Research Institute, Karnal, India.
48. Ranjeet, K. (2003). Studies on the manufacture of basundi using conical process vat. M. Sc. Thesis, NDRI, Karnal.
49. Rizvi, S. S. H., Mann, R. S., & Ali, S. I. (1987). A case study of appropriate technology transfer: Development of an automated continuous khoa powder manufacturing process. *Indian Dairyman, 39*, 63.
50. Singh, A. K., & Dodeja, A. K. (2012). Manufacture of basundi using three-stage sshe. *Indian Journal of Dairy Science, 65*(3), 197–207.
51. Upadhyay, J. B., Bhadania, A. G., Christic, I. S., & Shah, U. S. (1993). Manufacture of khoa based sweets and other food products on SSHE: an encouraging experience. *Indian Dairyman, 45*, 224.