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Detection of Spoilage in Canned Pasteurized Milk Using the Radiographic Imaging Technique

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ABSTRACT

After packed into sterilized containers with a closed and rigorous process, pasteurized milk has been ensured for its hygiene and safety factors. However, distortions can occur during storage and transportation, causing the container to open, allowing harmful microorganisms to enter and damage the product. This research proposed a radiographic imaging technique to detect and evaluate the spoilage of canned pasteurized milk. The X-ray images show that the milk cans, which were left open for three days at 300 K, indicated regions with abnormal density with the smallest detectable size from 100 µm or larger. Density heterogeneity would be clearer in the following days and depending on the sample. An algorithm was developed to identify spoilage products automatically with an accuracy of up to 100 % and a speed of 0.0057 s/product. This approach may be suitable for industrial scale to control the quality of dairy products.

INTRODUCTION

Milk is an essential food and is widely consumed around the world. Effective quality control is a critical challenge for dairy industry. In the process of storing before leaving the factory, because of an external impact, microorganisms can penetrate into the milk can. Milk is an ideal environment for microorganisms to grow. When there are predominant microorganisms, deterioration of products is a possibility. As milk spoils, the increase of number of bacteria leads to higher metabolism levels of lipid and protein counts and milk gelation and coagulation, also known as “curdling”, in stored milk [1]. There are many methods and tests to measure milk quality, such as Bacterial counts [2], Polymerase chain reaction (PCR) [3,4], and the Ultrasonic method [5-7]. These methods have high sensitivity and accuracy. However, biological techniques are slow and destructive, and they are difficult to automate. Ultrasound is a non-destructive testing method that has been used extensively in investigating the physicochemical properties of food and the types of contamination [6,8-10]. It employs contact ultrasound measurement using piezoelectric transducers. Therefore, in some instances, the use of the coupler makes inspection difficult, especially in those that need automatic.

The quality of pasteurized milk is controlled by not having any air traces inside its package. Many manufacturers, especially in low-tech factories, use random assessment of products by measuring pH, acidity, the number of microorganisms, etc. This method does not guarantee that all products are tested before they are delivered to the consumer. Current product control trends evolve towards reducing testing times, improving process sensitivity, and automating processes to reduce storage requirements and product failure. Nowadays, with high-speed computing and high-resolution detector arrays, the X-ray imaging technique has met the demands of these trends. It has been quite effective in many detection tasks with packaged foods in the manufacturing line, especially detecting foreign bodies in food [11-14]. This is a necessary system in many food processing factories. This study presented radiation imaging methods applicable to the visual and automatic inspection of damaged canned dairy products. It is

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based on the principle of density heterogeneity detection.

METHODOLOGY

The X-ray imaging system consists of an X-ray generator and a flat-panel detector arranged as shown in Fig. 1. The X-ray generator emits 0 - 150 kV of energy and 0 - 1200 μA of current. The focal spot size is 4 μm, which is small enough to improve the spatial resolution of projection images. The flat-panel detector's size is 116 × 33 × 1 mm^3 with a resolution of 2352 × 2944, and each pixel size is 49 μm.

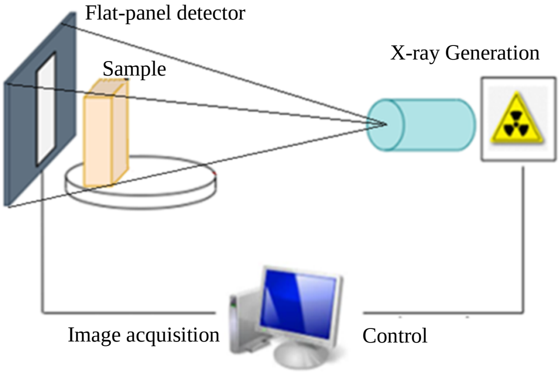


Fig. 1. Diagram of radiographic imaging system.

The five most popular types of pasteurized fresh milk produced in Vietnam were collected, each with 20 samples. All the canned milk samples were pierced with a hole of small size that allowed air to penetrate inside. They were left in a room at normal temperature and pressure for about ten days. They were monitored continuously from the first day to the tenth day by the X-ray imaging system. The optimum high voltage and output current for capturing radiation images of those samples were 140 - 150 kV and 800 - 1000 μA, respectively. The time to measure X-ray radiation was about 0.04 seconds for each sample.

When the milk packages were punctured, air would intrude into inside, and this leads to many microorganisms damaging the milk. The milk was thickened under microorganisms' effect, forming dense protein clumps or pores, or causing dehydration, or creating a solution of heterogeneous density. When X-rays passed through the milk solution, decrease of X-ray intensity at different density regions would be distinct. The resulting gray level at the corresponding points on the image would be different (see Fig. 2). Figure 2 shows that the gray levels in the radiographic image of the original milk sample are uniform. Meanwhile, the radiographic of the exposed milk sample on the fourth day shows many places with abnormal gray levels. The abnormality could be perceived with the naked eye. In this study, to facilitate the test's automation, a data-processing program had been set up to evaluate this anomaly automatically.

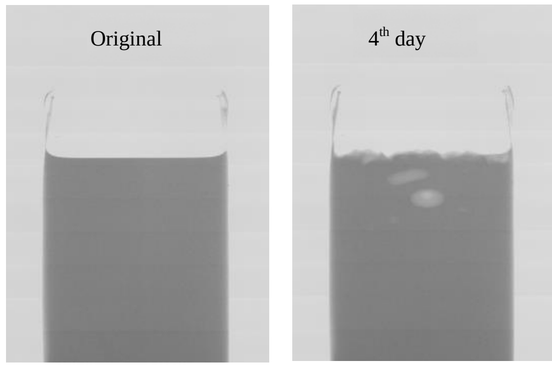


Fig. 2. Radiographic images of a sample in the original state and on the 4th day after air infiltration.

This study proposed two methods to automatically identify spoiled milk samples based on the obtained X-ray images. The images underwent pre-processing to normalize in size and remove the pixels outside the objects. For intact milk samples, the solution composition is relatively homogeneous, so the gray levels on their obtained images are similar, depending mainly on the quality of the flat panel detector. Therefore, the mean gray level of the intact milk samples was set as the threshold value for further processing. In both methods, we used the index σ(x,y) defined as follows in Eq. (1)

$$\sigma(x,y) = \frac{g(x,y)-g_t}{g_t} \quad (1)$$

where g(x,y) is the gray value at position (x,y), gt is the average gray value on X-ray images of an original sample.

The first algorithm was developed based on the K-mean clustering algorithm [15,16] to identify regions with higher gray levels than the device value set up above as Eq. (2). The gray level images of the samples were converted to binary images with the corresponding values as follows:

$$I(x,y) = \begin{cases} 1 & \text{if } \sigma(x,y) > \theta \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

where I(x,y) is the value at position (x,y) on binary images of samples, θ is constant and can change to set thresholds for Eq. (2).

One milk sample was considered spoilage if its radiographic image had at least one abnormal area size 2 x 2 $pixel^2$ or larger. As such, the smallest area detected by this method is the size of 100 x 100 μm^2. The method's accuracy depending on the value of θ was also investigated. Figure 3 shows binary images of a milk sample after transformation as in Eq. (2) with different values of θ. It can be seen that the higher value of θ, the smaller the area of the abnormal regions in the image. If this value is too high, the sensitivity of the method will decrease. However, it needs to be selected more elevated than the detector's errors.

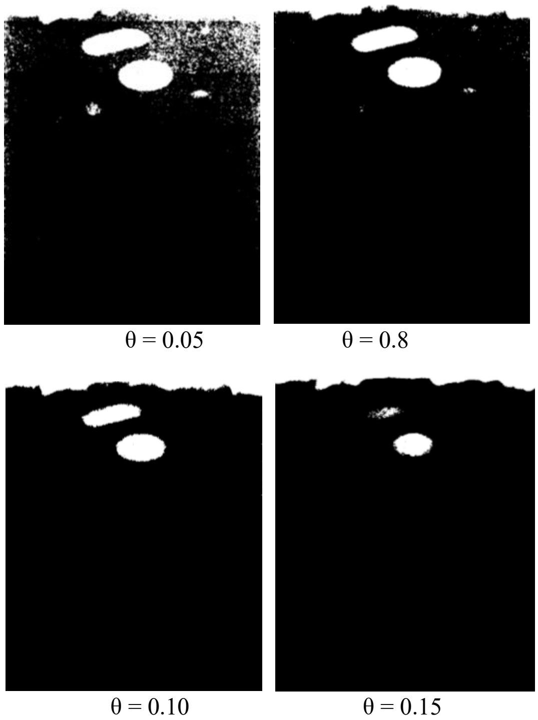


Fig. 3. Binary images of a milk sample after transformation as in Eq. (2) with different values of θ.

The second algorithm was based on the abnormal signal in the rows of the image. The top layer of the milk solution would be the first part to come into contact with microorganisms, where the milk molecules would slowly decompose and penetrate deeper down. Lighter density components would subsequently be produced, which also tended to be pushed upwards and progressively increased these irregular regions at the top of the milk carton. Therefore, anomalies in the gray level of the radiographs of spoiled milk samples will appear first in the first rows (see Figs. 4 and 5). Figure 5 shows the graphs of the 5th row's relative gray level distribution at various times from the contact surface of a milk sample and air. Because there were few density anomalies in the milk solution on the first day, the relative gray levels of the points in the 5th row of the image matrix were the same. During the next few days, many biochemical changes happened in the milk solution, resulting in many regions with densities that differed from the average value. As a result, there were points within the same row with a relative gray level higher or lower than the average (red line). Based on these differences between positions in the same row of the image matrix, heterogeneity of milk could be detected.

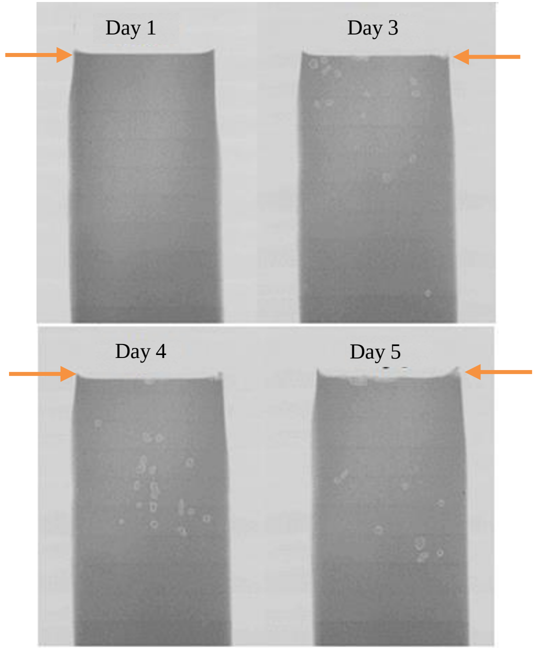


Fig. 4. Radiographic images of a milk sample at different times since air entered the package.

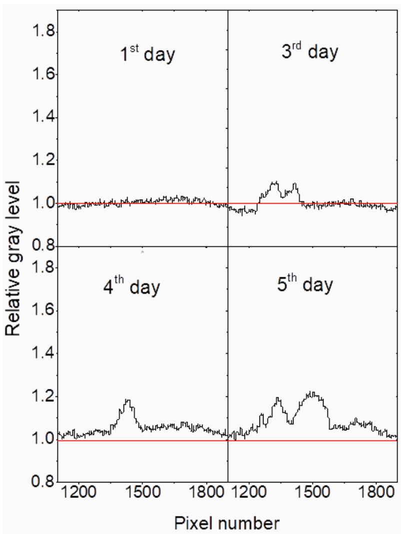
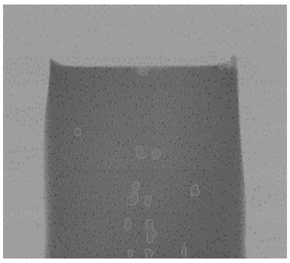


Fig. 5. Relative gray level distribution plot of row number 5 from the interface of milk solution and air (position as the name zone shown in Fig. 4).

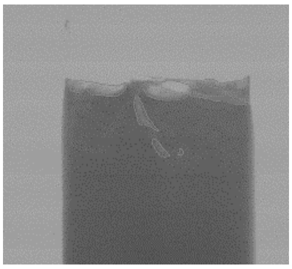
To ensure the reliability of the algorithm, the first ten rows of the milk solution was evaluated. When there were two consecutive rows with at least two adjacent positions with the value σ(x,y) >0, the image was classified as an error or damaged sample. The accuracy, sensitivity, and computational speed of this algorithm were also investigated and presented below.

RESULTS AND DISCUSSION

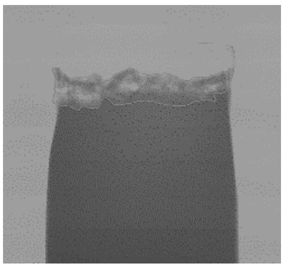
The X-ray images from the 3rd to 10th day show abnormal regions caused by microbial infiltration under favorable environmental conditions (see Fig. 6). It can be observed on the radiographs abnormal regions with various shapes, such as nodules, spots, and air bubbles (gray level nearly same to air). Different canned milk samples produce indications in the other regions, but most of them appear first near the air-exposed surface of the milk solution.



(a)



(b)



(c)

Fig. 6. X-ray images of some damaged milk samples. Samples (a); (b); (c) were damaged after 4, 6, and 7 days, respectively, from air-exposed.

The images of milk samples collected at different days from air entry into the milk carton were evaluated by two automatic identification algorithms as described above. For the first method, the accuracy depends on the θ value. Figure 7 shows that in the first days, the accuracy of the method is not high. For the first day, very few samples show abnormal regions. There are only less than 5 % of milk samples that were damaged. Nevertheless, in the following days, the biochemical processes in the milk solution occurred more actively, causing an increase in changes that made the milk solution exhibit more anomalous regions. As a result, the method's accuracy when examining these samples increases, and up to 100 % accuracy can be achieved (from day four onwards). The value of θ was changed from 0.05 - 0.15.When evaluating samples in the early days, the method’s accuracy would be more accurate when using θ with low values than with high values. However, if this value is too low, identifying anomalies is easily confused due to random errors and instrument errors. We chose the minimum value of θ is 0.05.

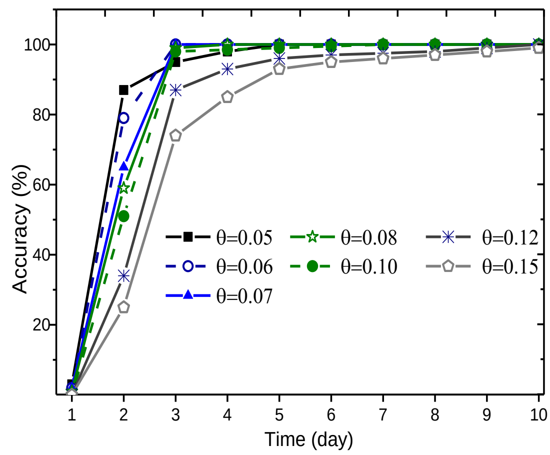


Fig. 7. The accuracy of the first evaluation method following the value of θ and the test date.

Table 1 indicates the accuracy of the method depending on the value of θ and the test date. For milk samples exposed to air for about three days or more, the method's accuracy can reach 99.88 % if θ = 0.06 - 0.08. Evaluating an image of this method took 0.0200 seconds for a computer with a 2.7 GHz CPU.

Table 1. The accuracy of the first method following the value of θ and the test date.

	From 2nd day	From 3rd day	From 4th day
θ = 0.05	97.78	99.13	99.71
θ = 0.06	97.67	99.88	99.88
θ = 0.07	96.11	99.88	99.88
θ = 0.08	95.33	99.88	99.88
θ = 0.10	94.00	99.38	99.38
θ = 0.12	89.06	95.94	95.94
θ = 0.15	84.67	92.13	92.13

For the second method, when the radiograph of the sample shows some abnormality, the gray level value in a row can change about 5 ÷ 65 % in all surveyed samples (see Fig. 4). For the milk samples that had been exposed to air for 1 ÷ 2 days, the accuracy of this method is very low, less than 10 %. The method gives higher accuracy for the samples exposed to air from three days onwards, about 95.43 %. From four days onwards, the method accuracy is 100 %. The evaluation time for an image of the method is only about 0.0057 seconds. Thus, the first method gives higher accuracy and sensitivity than the second method. However, the execution time of the first method is 4 times slower than that of the second method.

When air enters the inside of the milk container, if observed with the naked eye, the milk solution almost does not have any spoilage, solidification, or fermentation on the first day. Therefore, the radiographs of these milk samples indicate almost no abnormal regions. Using two classification methods in this study can notice it. From the production point of view, products that have air infiltrated inside must be discarded. Research [8-10] has shown that ultrasound can detect air in package milk in the first days. The method may not be as sensitive as the ultrasound method, but it can be deployed for industrial-scale inspection that is hard to do with ultrasound. The first method has higher accuracy for the automatic classification of samples, but the execution time is longer than the second one. This classification can also be applied by artificial intelligence, but the research [11] showed that the implementation is quite long, and the accuracy is not high. Thus, the application of radiographic techniques in identifying spoiled milk samples when exposed to air is completely feasible and can be applied on an industrial scale. The method shows high accuracy and faster time than probability testing in some factories today.

CONCLUSION

Radiographic techniques with suitable specifications can help us observe density anomalies inside pasteurized milk samples. The method can evaluate and remove damaged canned milk products before market. Research has proposed two methods of automatic image recognition to detect spoilage in milk solution with accuracy up to 100 % and sorting speed from 0.0057 - 0.0200 s/product, depending on the computer's configuration. This study indicates that radiographic technology can be used to detect contamination or spoilage of canned milk with high speed and high accuracy, which can be applied at an industrial scale.

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AUTHOR CONTRIBUTION

Duong Tran Thuy - First_author and Hung Bui Tien - Second_author equally contributed as the main contributors of this paper. All authors discussed the results presented in the manuscript, read and approved the final version of the paper.

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