Design and Development of an Automated and Quality Controlled System for Traditional Butter and Ghee Production

AHMAD ALJAAFREH
Department of Communication, Electronics and Computer Engineering,
Tafila Technical University, Tafila, 66110, JORDAN
a.aljaafreh@ttu.edu.jo
RIADH AL-TAHIRI
Al-Tahiri and Al-Kawaleet Dairy Company, Ader, Karak, JORDAN
rdtah2001@yahoo.com
AHMAD ABADLEH
Department of Computer Science,
Mutah University, Mutah, 61710, Karak, JORDAN
ahmad_a@mutah.edu.jo
AYMAN M. MANSOUR
Department of Communication, Electronics and Computer Engineering,
Tafila Technical University, Tafila, 66110, JORDAN
mansour@ttu.edu.jo
MURAD ALAQTASH
Department of Communication, Electronics and Computer Engineering,
Tafila Technical University, Tafila, 66110, JORDAN
mmalaqtash@ttu.edu.jo

Abstract: - Traditionally, Jordanian butter has always been made from yogurt. Raw milk of sheep are collected, fermented, and then churned by mechanical shaking until butter granules are formed. After extracting the butter, the remaining buttermilk, called *Makheedh* or *Shaneena* in Jordan, is used to produce a type of dry yogurt called *Jameed*, a local dairy product in Jordan. The traditional process of churn and Jameed production is primitive and time-consuming. Moreover, many challenges may affect the quality of products such as poor sanitation, lack of effective milk cooling, and absence of milk pasteurization. Observations made of traditional butter-making by smallholders have indicated that the process should be improved by increasing the efficiency of fat extraction from the yogurt and reducing the processing time, thereby improving the economic return.
The main objective of this work is to automate the process of traditional Jameed and butter production, as well as improve the quality of the products. To achieve this goal and overcome all production problems of the traditional process, a system was designed and developed to churn milk and produce butter rapidly and consistently. Several experiments were performed to select the optimal churn parameters such as rotor velocity, churn temperature and time. Many experiments were also performed to select the best sensors that can be used to control the whole process including heating, cooling, fermentation, and churn.

Key-Words: - Dairy Mechanization, Butter Churn, Process Automation, Quality Controlled, Jordanian Jameed.

1 Introduction

The butter churn process used to make butter by shaking up the yogurt. The agitation of yogurt is done by mechanical motion, which disrupts fat globules and changes emulsion from oil in water to water in oil. Butter grains are formed by breaking down the milk fat globules membranes [1]. The churn causes these grains to fuse from each other and then form the butter. The liquid left out without fat is called buttermilk. Butter churns have been varied over time. Early local butter churns were made of animal materials like animal leather. Later, other materials like wood, metal or glass were used as containers to churn butter. In a manual churn process, a human being decides to end the churning process when a satisfying quantity or quality of fat or buttermilk is collected. The local churn process is still a manual process although there were many attempts toward churn automation [2], [3], [4], and [5].

Locally, the raw milk of sheep is processed to produce buttermilk, butter, ghee, and Jameed, local and traditional homemade products in Jordan. Fig. 1 illustrates the traditional process of Jameed and ghee production from sheep milk. The process starts by collecting milk, usually using plastic or aluminum containers with very low standards of cleaning. Workers then heat the milk to the fermentation temperature by a direct gas fire following by adding the starter (yogurt) to the heated milk for the fermentation process. Through the fermentation, the milk is incubated at a warm temperature for at least three hours. Starter bacteria convert lactose to lactic acid which converts the liquid milk to a jelly-like yogurt. A fter fermentation, the product is cooled by adding chilled water and ice to start churn. Most of the time, churn is done using a plastic container with low hygiene standards. The churn usually takes about one hour to make the butterfat float on the surface. Workers collect the butterfat and store it in plastic drums. The produced butter is usually transformed into ghee by cooking butter with at least ten different herbs to overcome the rancidity taste. The heat evaporates the water and concentrates the fat in the ghee. Furthermore, Jammed is produced from buttermilk which is called Makheedh or Shaneena in Jordan. The buttermilk produced after churn is heated without agitation to allow the whey to be separated from the buttermilk. The heated buttermilk is then filled in a cloth bags, adding salt to it, and then kept for three days to remove the whey as m uch as possible. After that, the dehydrated buttermilk is mixed by hand and formed as balls of Jameed. Jammed balls are then dried and became ready to be sold in the market.

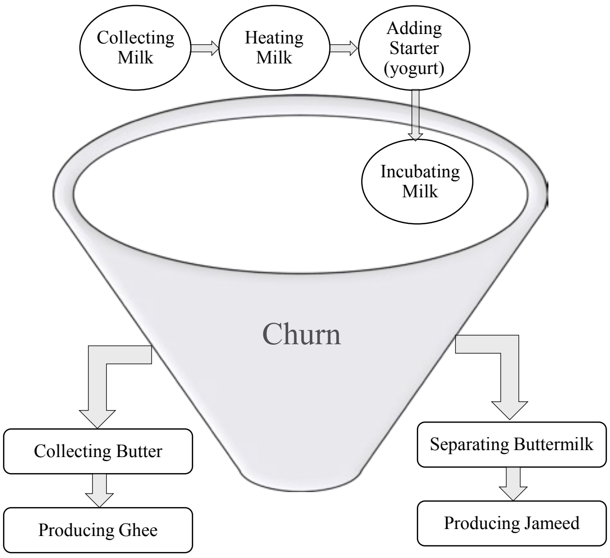

Fig. 1. The traditional process of Jameed and ghee production from sheep milk.

The traditional process of Jameed and ghee production in Jordan is primitive and time-consuming. Moreover, many challenges may affect the quality of products such as poor sanitation, bad microbiological quality of milk due to bad hygiene during milking, lack of effective milk cooling, and absence of milk pasteurization. Plastic and aluminum containers are usually used in all processing steps, both of them are not suitable for food production. Furthermore, lack of cooling in the milk collection stage reduces the quality of milk due to the growth of microorganisms which leads to acidity development and production of many materials that badly affect the human health and production process [6]. Enzymes activity accelerated due to high storage temperature leads to fat degradation which produces rancidity in the final products especially the ghee. While protein degradation gives rise to unwanted taste in the Jameed. The absence of milk pasteurization leads to a very dangerous health situation due to the transfer of milk-borne disease from animal to human as shown in Table 1. Many other microorganisms can contaminate the milk from the farmer, the workers, and the environment which can affect badly human health and the process. There is no control equipment for heating and cooling of the milk and the products, fermentation process and the acidity development of the milk and churning processes. Also, direct gas fire for heating can rise coked flavor and brown color to the final products. A dding chilled water and ices to the products for cooling increase the possibility of contamination.

Table 1. The causative organisms of diseases from animal to human.

Disease	Causative organisms
Mastitus	Staphylococcus aureus Streptococcus uberis Streptococcus agalactiae Escherichia coli Listeria monocytogenes
Johne's disease	Mycobacterium avium Subsp paratuberculosis
Tuberculosis	Mycobacterium bovis Mycobacterium tuberculosis
Brucellosis	Brucella abortus Brucella melitensis

Local butter, fat, ghee, and Jameed are all almost homemade products. C onsumers and food makers who use local products always demand to have their foods of higher standards and better quality. Nutritional value, health benefits, and safety are essentials to food quality.

Automation is using technologies to operate machines and systems without human intervention to achieve higher operation performance than manual operation [7]. Sensors, actuators, and controllers are the three main components of the industrial automation system.

The ultimate goal of this work is to automate the process of Jameed and butter production, as well as improve the microbiological quality of the products to get hygienic products. Automation ensures high-quality products with excellent flavors and a high solubility characteristic for Jameed and butter.

The rest of this paper is organized as follows: Sec.2 presents the system design. Followed by the Jameed manufacturing process in Sec.3. Then, Sec.4 describes the experimental methodology and setup. The experimental results are discussed in Sec.5. Sec.6 presents the conclusion.

2 System Design

Fig. 2 shows the system developed in this work to automate the churn process. It consists of a 200-liter stainless tank with a drain outlet. The churn tank is made of a grade food stainless steel to ensure that churn in a sterilized and avoid any contamination. This tank is equipped with a cooling system to cool the raw milk inside the tank and control the temperature during churn process. The refrigerator cooling system is composed of a refrigerator compressor, temperature sensor, and a water jacket layer around the tank to heat or cool the product automatically. The system also contains a special agitator which can move in different speeds. A low speed for agitating the milk and the product during heating and cooling and a high speed for churning the yogurt. The agitator has a single phase electric motor 240V attached with a stainless round shape shear impeller with a diameter of 15 cm and sharp teeth as shown in Fig. 3. The main controller consists of motor drive, inverter, to control motor speed, timer to set the timing parameters, and temperature control keypad to set the desired churn temperature.

The system is equipped with many sensors to control and monitor the heating, fermentation, and churn processes. Conductivity is measured by electrodeless conductivity stick meter 5JI. To automate the churn process, a proper sensor is needed to end the churning process when a sufficient amount of butter is collected [8] and [9]. We assumed that the conductivity, density, and viscosity changes according to the process. This assumption is based on the fact that when the butter is extracted from the yogurt the conductivity increases since butter has low conductivity. Buttermilk has a higher density than yogurt since butter is lighter than water. This is also applied for viscosity. To prove the concept, many experiments were performed by measuring conductivity, density, and viscosity before and after the churning process.

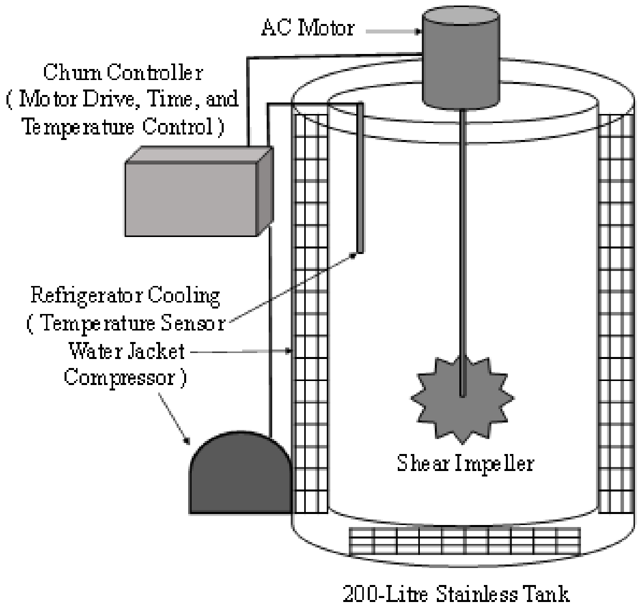

Fig. 2. The developed system to automate the churning process. The architectural design of the system is shown on the right side which illustrates the main components of the system. The manufactured system is on the left side.

Fig. 3. A stainless shear impeller used in the system

3 Jameed Manufacturing Process

The Jameed manufacturing process which has been followed by this work is described as follows:

Step 1. Milk Storage: The raw sheep milk is stored in the processing tank and cooled down to 4°C. Cool storage of milk keeps it with high quality, preventing the growth of microorganisms, and stop the activity of enzymes.

Step 2. Milk pasteurization: the milk is pasteurized at 90°C for five minutes. This high heat treatment brings about a number of chemical, microbiological and physical changes: kills contaminating and competitive organisms, Production of growth factors by a breakdown of milk proteins, and heat-induced interaction between casein and denatured whey protein to create body and texture for the yogurt. Denaturation of whey proteins increases their water-binding capacity.

Step 3. Milk fermentation: The milk is cooled down inside the tank to 43°C as an optimum temperature for the growth of the starter organisms. Starter culture at a level of 2% is added to the milk, the starter contains the following bacteria: Lactobacillus Delbrueckii Subsp. Bulgaricus and Streptococcus Thermophiles. Starter bacteria convert lactose to lactic acid, pH reduced to 4.5-4.6, and develop flavor compounds especially acetaldehyde. Association growth between Lactobacilli and Streptococcus increases the rate of acid and flavor production [10] and [11].

Step 4. Yogurt Cooling: Produced yogurt cooled down to 14°C to start churn.

Step 5. Churn: The churn process makes a foam of large protein bubbles due to yogurt agitation. Being surface-active, the membranes of the fat globules are drawn toward the air/water interface and the fat globules are concentrated in the foam. When agitation continues, the bubbles become smaller as the protein gives off water, making the foam more compact and thereby applying pressure on the globules. This causes a certain proportion of the liquid fat to be pressed out of the fat globules and causes some of the membranes to disintegrate. The liquid fat, which also contains fat crystals, spreads out in a thin layer on the surface of the bubbles and the fat globules. As the bubbles become increasingly dense, more liquid fat is passed out and the foam is soon so unstable that is collapsing. The fat globules coagulate into grains of butter, at first, these are invisible to the naked eye. But they grow progressively larger as work continues [11], [12], [13], and [14].

Step 6. Butter Collecting: The floated butter granules are collected by sterilized sieve made of stainless steel and kept at low-temperature storage to be used for ghee production. Conductivity, density, and viscosity can be used to follow the progress of the churn.

Step 7. Buttermilk heating: The buttermilk which been left inside the tank after removing the butter is heated up to 55°C with no agitation to help in whey separation.

Step 8. Jameed Production: The buttermilk is packed in cloth bags through a butterfly valve build-up at the bottom of the tank. Cloth bags will be left under pressure for at least three days to remove the whey, then the final product, Jameed, is shaped to a round-shape and dried.

4 Experimental Results and Discussion

4.1 Optimizing the Churning Process

The developed churn control parameters needs to be optimized. These parameters are the rotational speed and temperature. The amount of fat in butter and churning time are directly proportional to the speed of rotation. Secondly, the churning temperature of yogurt or cream. As the temperature of the yogurt goes lower, it helps to have larger amount of butter. However, it increases the churning time. Electrical available churn rises the temperature of yogurt during the agitation process.

4.1.1 Optimal Speed

The goal of this stage is to optimize the churning process to minimize the churning time. The relation of the impeller speed to the churning time is required to achieve the required product quality. We churn on three different impeller speeds as in Table 2. We have found that the churning time decreases as the impeller angular speed increases. Electrical available churn faces many problems such as the lack of control sensors to start and end fermentation and churning process.

Table 2. Relation between impeller angular speed and churning time.

Exp. #	Impeller angular speed (rpm)	Churning time (minutes)
1	1000	110
2	1000	120
3	1000	118
4	1500	55
5	1500	59
6	1500	58
7	2000	35
8	2000	32
9	2000	35

4.1.2 Optimal Temperature

The goal of this stage is to optimize the churning process to know the optimal temperature of the yogurt for the churning process. Thirteen experiments were performed and listed in Table 3. Yogurt at five different temperatures were churned for different periods. Churning time is the time it took to ripen the yogurt. We noticed that fat does not crystalize unless adding hot water to rise temperature to 12 ºC. Butter was very soft and difficult to be collected at temperature above 18 ºC. We have found that the best temperature is 12 ºC.

Table 3. Churning optimization including churning time, yogurt temperature and buttermilk temperature, measured at the end of churn.

Exp.#	Yogurt Temperature (ºC)	Churning time (minutes)	Buttermilk Temperature (ºC)
1	6	120	11
2	6	125	11
3	6	130	12
4	8	125	12
5	8	130	13
6	8	124	13
7	10	90	14
8	10	100	14
9	10	96	14
10	12	50	16
11	12	52	18
12	12	51	18
13	14	50	19

4.2 Experiment at Optimal Parameters (Speed and Temperature)

The main goal of the experiments conducted in this paper is to choose which parameter can be used to start and end churn process automatically among conductivity, viscosity and density. The conductivity, density, and viscosity of the milk under process were read before and after the churn process.

4.2.1 Conductivity

Conductivity is measured by electrodeless conductivity stick meter 5JI as in Table 4. Churning efficiency in terms of the amount of collected butter is shown in Table 4. Ripening can be recognized by checking conductivity and time needed.

Table 4: Conductivity (4 trials with the optimal condition)

Exp.#	Conductivity before churning (μS)	Conductivity after churning (μS)
1	7450	9230
2	7140	9110
3	7240	9190
4	7220	9110

4.2.2 Viscosity

Viscosity is measured with simple method by running 200 ml of yogurt at 20 ºc through a 250 ml separating funnel and measure the time it takes to pass through the nozzle of the separating funnel as in Table 5.

Table 5. Viscosity (4 trials with the optimal condition)

Exp.#	Viscosity before churning (second)	Viscosity after churning (second)
1	35	18
2	41	20
3	38	18
4	40	19

4.2.3 Density

Density was measured by weighting 25 ml of product as shown in Table 6.

Table 6. Density (4 trials with the optimal condition)

Exp.#	Density before churning (g/ml)	Density after churning (g/ml)
1	0.99	1.11
2	1.02	1.13
3	1.01	1.11
4	1.03	1.13

Several remarks can be drawn based on t his Table. Density increases after churning since the density of the butter milk is greater than the density of yogurt since it losses the fat which is lighter than water

4.3 Efficiency (butter percentage)

Churning recovery (yield) is a m easure of how much of the fat in the yogurt has converted to butter. The first factor that effects on the amount of butter and agitation time is the proportion of fat in yogurt (or cream). The higher the percentage of fat in the yogurt is the higher is the proportion of fat in the resulting butter. The second factor is the degree of cleanliness of yogurt. The third factor is the amount of water added during the churning process. Water used in this process lowers the percentage of fat in resulting butter. The last factor is the process time (fermentation and churning).

Churning recovery (yield) is a measure of how much of the fat in the yogurt has converted to butter. is expressed in terms of the fat remaining in the buttermilk as a percentage of the total fat in the yogurt (Table 6). For example, a churning recovery of a 0.5 m eans that a 0.5% of the yogurt has remained in the buttermilk and 99.5% has been tuned into butter. Churning yield is considered acceptable if the value is less than 0.7 [15],[16],[17]. The yield in our tank is as in Table 7. Fat measurement has been done by a v ery precise method called Majonnier which depends on weight of extracted fat. These results show that churning process considered acceptable.

Table 7. Churning recovery (yield).

Batch no.	Yogurt fat (%)	Buttermilk fat (%)
1	6.8	0.37
2	6.9	0.46
3	7.1	0.51
4	7.2	0.49
5	6.9	0.52

Table 8. Churning efficiency in terms of the amount of collected butter (2 trials with optimal condition).

Yogurt amount (kg)	Milk fat (%)	Butter weight with 80% fat (kg)	Milk total fat weight kg	Butter total fat (%)	Churning efficiency (%)
100	7.8	8	7.8	6.4	82
100	7.6	7.5	7.6	6	78.9

5 Conclusions

Dairy products form one of the fastest growing segments in the livestock products in Jordan. In this paper, the churning and fermentation process is automated for the local organic butter, fat and Jameed manufacturing. This study is based on an extensive study of user requirements. We did field visits to all dairy factories in Karak governorate like Ader, Msherfh, and the college of agriculture at Mutah University. We also met with the president of the sheep breeders association and a g roup of breeders. We have discussed the problems related to the process of milk churning. There was a consensus on the urgent need for a station that could do pasteurization, fermentation and churning automatically without human interference. This leads to a product of good quality and high safety.

A system design is proposed in this paper to automate a manufacturing process for the production of the local organic butter, fat and Jameed. Automation is based on fluid conductivity, temperature and time. To the best of our knowledge we are the first who think of automating such kind of manufacturing process.

References:

[1] Walstra, P., *Dairy technology: principles of milk properties and processes*. CRC P ress, 1999

[2] Funahashi, H., & Horiuchi, J., Characteristics of the churning process in continuous butter

manufacture and modelling using an artificial neural network, *International dairy journal*, 18(3), 2008, 323-328.

[3] Gonfa, A., Foster, H. A., & Holzapfel, W. H., Field survey and literature review on traditional fermented milk products of Ethiopia, International Journal of Food Microbiology, 68(3), 2001, 173-186.

[4] Avramis, C. A., Wang, H., McBride, B. W., Wright, T. C., & Hill, A. R., Physical and processing properties of milk, butter, and Cheddar cheese from cows fed supplemental fish meal, Journal of Dairy Science, 86(8), 2003, 2568-2576.

[5] Aljaafreh, A., Butter churning process automating based on acoustic signals, Journal of Computing, 3(5), 2011, 38-41.

[6] Farah, Z., Streiff, T., & Bachmann, M. R., Manufacture and characterization of camel milk butter, Milchwissenschaft-Milk Science International, Germany, 44(7), 1989.

[7] Aljaafreh, A., Agitation and mixing processes automation using current sensing and reinforcement learning, Journal of Food Engineering, 203, 2017, 53-57.

[8] Aljaafreh, A., & Lucklum, R., On-line monitoring of yogurt fermentation using ultrasonic characteristics. New Developments in Circuits, Systems, Signal Processing, Communications and Computers, Vienna, Austria, 2015.

[9] Aljaafreh, A., & Steiner, H., Evaluation of using NIR simplified spectroscopy in Yogurt fermentation automation, Spectroscopy, 73(10), 2015, 11.

[10] Skeie, S., Characteristics in milk influencing the cheese yield and cheese quality, Journal of Animal and Feed Sciences, 16(1), 2007, 130-142.

[11] Tamime, A. Y. (Ed.), Dairy fats and related products, John Wiley & Sons, 2009

[12] Robinson, R. K. (Ed.), Dairy microbiology handbook: the microbiology of milk and milk products, John Wiley & Sons, 2005

[13] Chandan R. C., & Kilara, A., Manufacturing yogurt and fermented milks, John Wiley & Sons, 2013.

[14] Frye, C. P., & Kilara, A., Milk from farm to plant, Wiley-Blackwell, 2015.

[15] Griffiths, M. (Ed.), Improving the safety and quality of milk. Woodhead Publishing Series in Food Science, Technology and Nutrition,2010, 482-498.

[16] Jones, A., Consumer willingness to pay and economic viability of speciality milk products (Doctoral dissertation, University of Plymouth).,2018.

[17] Papademas, P., & Bintsis, T. (2010). Food safety management systems (FSMS) in the dairy industry: a review. International journal of dairy technology, 63(4), 2010, 489-503.