DOI: https://doi.org/10.21323/2618-9771-2022-5-2-94-99

Received 31.03.2022
Accepted in revised 21.04.2022
Accepted for publication 29.04. 2022

Available online at https://www.fsjour.com/jour
Original scientific article
Open access

MILK CURD SELF-SEGMENTATION IN CHEESEMAKING TANK

Igor T. Smykov
All-Russian Scientific Research Institute of Butter- and Cheesemaking, Uglich, Yaroslavl Region, Russia

KEY WORDS:
milk gelation, cheesemaking, Benard cells, gel self-segmentation

ABSTRACT
The purpose of this work is to describe and study the previously unknown phenomenon of self-segmentation of a milk curd in an open-type cheesemaking tank. Based on the analysis of the kinetics of gel formation, it has been determined that self-segmentation of the gel begins near the gel point, develops over several tens of seconds, and becomes stable as the gel condenses. The segments in the milk curd do not have a definite regular shape; their average size varies from 5 to 50 cm. The shape and size of the segments do not repeat and do not correlate with the type of cheese being produced. The displacement of the segments of the milk curd in the cheesemaking tank relative to each other in height is from 0.5 to 2 mm. The width of the boundary layer between the curd segments increases during the secondary phase of gelation from 3 to 10 mm. As a result of experimental studies, it has been shown that self-segmentation of milk gel is caused by thermogravitational convection, which forms Benard convection cells. A description of a possible mechanism of milk gel self-segmentation in open-type cheesemaking tanks is proposed. The effective role of fat globules in the mechanism of self-segmentation of the milk curd has been noted. It has been suggested that self-segmentation of the milk curd in the cheesemaking tank may cause some organoleptic defects in the finished cheese, in particular inhomogeneity of texture and color.

FUNDING: The article was prepared as part of the research under the state assignment No. FNEN-2019–0010 of the “V. M. Gorbatov Federal Research Center for Food Systems” of the Russian Academy of Sciences.

ACKNOWLEDGEMENTS: The author expresses his deep gratitude to the experienced cheesemaker Natalya Moshkina, head of the experimental workshop of VNIIMS, for her invaluable assistance in conducting experimental research in the field of cheese manufacture.

Поступила 31.03.2022
Поступила после рецензирования 21.04.2022
Принята в печать 29.04.2022

https://www.fsjour.com/jour
Научная статья
Open access

САМОСЕГМЕНТАЦИЯ МОЛОЧНОГО СГУСТКА В СЫРОДЕЛЬНОЙ ВАННЕ

Смыков И. Т.
Всероссийский научно-исследовательский институт маслоделия и сыроделия, Углич, Ярославская область, Россия

КЛЮЧЕВЫЕ СЛОВА:
гелеобразование молока, производство сыра, ячейки Бенара, самосегметация геля

АННОТАЦИЯ
Цель этой работы состоит в описании и исследовании ранее неизвестного явления самосегментации молочного сгустка в сыродельной ванне открытого типа. На основе анализа кинетики гелеобразования определено, что самосегметация геля начинается вблизи гель-точки, развивается в течение нескольких десятков секунд и закрепляется по мере уплотнения геля. Сегменты в молочном сгустке не имеют определённой правильной формы, их средний размер вариабелен в пределах от 5 до 50 см. Форма и размеры сегментов не повторяются и не коррелируют с видом вырабатываемого сыра. Смещение сегментов молочного сгустка в сыродельной ванне относительно друг друга по высоте составляет от 0,5 до 2 мм. Ширина граничного слоя между сегментами сгустка увеличивается в процессе вторичной фазы гелеобразования от 3 до 10 мм. В результате проведенных экспериментальных исследований показано, что самосегментация молочного геля вызывается термогравитационной конвекцией, образующей циркуляционные ячейки Бенара. Предложено описание возможного механизма самосегментации молочного геля в сыродельных ваннах открытого типа. Отмечена действенная роль жировых шариков в механизме самосегментации молочного сгустка. Высказано предположение, что самосегментация молочного сгустка в сыродельной ванне может вызвать некоторые органолептические дефекты в готовом сыре, в частности неравномерность текстуры и неравномерность цвета.

ФИНАНСИРОВАНИЕ: Статья подготовлена в рамках выполнения исследований по государственному заданию № FNEN-2019–0010 Федерального научного центра пищевых систем им. В. М. Горбатова Российской академии наук.

БЛАГОДАРНОСТИ: Автор выражает глубокую признательность опытному мастеру-сыроделу Наталье Мошкиной, заведующей экспериментальным цехом ВНИИМС, за неоценимую помощь в проведении экспериментальных исследований в области производства сыра.

1. Introduction

Many thousands of experienced cheesemakers-practitioners and research scientists have observed the formation of rennet milk curd in open cheesemaking kettles, vats and tanks, but there is no mention in the literature of visible surface changes in the milk curd. Indeed, visually it is almost impossible to notice any changes on the surface of milk, except for the initial separation of whey, throughout the entire process of formation of

FOR CITATION: **Smykov, I. T.** (2022). Milk curd self-segmentation in cheesemaking tank. *Food systems*, 5(2), 94-99. https://doi.org/10.21323/2618-9771-2022-5-2-94-99

ДЛЯ ЦИТИРОВАНИЯ: **Смыков, И. Т.** (2022). Самосегментация молочного сгустка в сыродельной ванне. *Пищевые системы*, 5(2), 94-99. https://doi.org/10.21323/2618-9771-2022-5-2-94-99

the rennet curd. Especially if the milk is covered with foam that forms when the milk mixture is stirred.

The mechanism of the enzymatic phase of gelation in milk is well described in molecular terms in [1,2,3,4]. The influence of various environmental factors on it is quantitatively revealed. The initial aggregation of rennet-hydrolyzed casein micelles in this phase is confirmed by a series of micrographs obtained by different authors [5,6]. It is also noted that at the end of the enzymatic phase, cooperative conformational phase transitions occur in casein molecules, which drastically change the properties of casein micelles [7,8,9].

In the descriptions of the mechanism of the enzymatic phase of gelation, it is assumed that the milk is at rest, and the interactions between the enzyme molecules and κ-casein, intermicellar interactions of destabilized micelles occur due to the diffusion (Brownian) motion of particles. However, it is well known that agitation of milk in the fermentation phase prevents gel formation. The quantitative influence of the mixing factor and the intensity of residual movements of milk in the volume on the properties of the resulting gel remains unexplored.

The secondary phase of rennet coagulation [10] includes further aggregation of destabilized micelles, leading eventually to gel formation. The mechanism of micelle aggregation in this phase can be described by the von Smoluchowski theory for diffusion-limited aggregation (DLA) [11,12]. Diffusion of particles limits the rate of aggregation and is determined by random collision and connection of particles of destabilized micelles [13]. However, even for this phase of coagulation, the known models of gelation do not take into account the effect of mixing milk on the properties of the gel. In addition, the mixing of milk can occur spontaneously, both due to conformational transitions in casein micelles at the micro level [8], and due to convective flows in the cheesemaking tank at the macro level.

Gelation, which occurs under conditions of relative rest, is the conversion of milk from a colloidal dispersion into a continuous protein phase, which includes moisture and fat globules in its pores. A number of physicochemical changes accompany such a conversion in the system, for example, the light reflectance and thermal conductivity change. These changes can be used and are used to evaluate the kinetics of gelation in milk in various studies and in the industrial production of cheese.

It is obvious that the main attention of researchers is drawn to the disclosure of the patterns of rennet gelation at the microscopic level. However, for cheese manufacturers it is primarily important to ensure the high quality of cheeses, their attractiveness to consumers. Therefore, it is necessary to have clear ideas about at what stages of the cheese manufacture technology certain defects in the finished product may occur [14]. Much attention is also paid to this area of research. Thus, in [15] it is noted that in the United States of America up to 5% of produced cheese is lost or becomes less valuable due to quality problems annually. However, some manufacturers report large losses of 20 to 30% of their product due to quality defects.

The work [16] is devoted to the problems of assessing the quality of cheese texture, its defects and measures to prevent their occurrence. Texture plays a key role in consumer perception and the market value of cheeses. Therefore, the texture of food products is assessed using instrumental and organoleptic methods, which are discussed in [17]. The texture of cheese is directly related to its microstructure and therefore various microscopy methods are of great importance here [18]. This review discusses advances in the analysis of the microstructure of cheese, including new methods and how they can be applied to understand and improve the quality of cheese. Simultaneous assessment of the texture and color of cheeses can be performed using the segmentation algorithm of the cheese fracture image in the color space [19]. For expert evaluation, a specially developed Likert scale was used.

Despite the fact that there are many theoretical and experimental studies on the process of gelation in milk, little attention has been paid to the influence of the size, shape and design of the reservoirs in which the formation of a milk curd occurs on its sensory characteristics.

The purpose of this study was to describe the discovered phenomenon of self-segmentation of a milk curd in a cheesemaking tank, to identify its causes, to determine the manifestations of self-segmentation and its possible impact on the quality of a milk curd.

2. Objects and methods

The studies were carried out in the experimental production workshop of the All-Russian Scientific Research Institute of Butter- and Cheesemaking, a branch of the V. M. Gorbatov Federal Research Center for Food Systems".

In the studies, cow's milk was used from one supplier-manufacturer — AgriVolga LLC, Yaroslavl region, Uglich district, Burmasovo village.

Rennet enzyme 90, Extra (chymosin — 90%, beef pepsin — 10%), MSA — 100000 were used in the studies. Plant of endocrine enzymes, Moscow, Zelenograd, Russia;

Cheese manufacture was carried out in an industrial-experimental cheesemaking tank with a volume of 300 liters according to standard technological production processes: heating and pasteurization of milk in a tank at a temperature of 68 °C for 10 minutes; milk cooling; the addition of calcium chloride, liquid bacterial starter and enzyme preparation; mixing and coagulation of milk at a temperature of 35 ± 1 °C, cutting and further operations for cheese molding.

Studies were carried out in the manufacture of commercial semi-hard cheese "Rossiyskiy" — the mass fraction of fat in dry matter is 50%, the mass fraction of moisture is 43%;

The change in viscosity during the formation of a milk curd in a cheesemaking tank was assessed by the change in its thermal conductivity by the hot wire method [20,21,22]. In preparation for the research, an automated system for in-line control of the process of gelation kinetics in a cheesemaking tank was used, described in [23].

Additionally, two platinum resistance thermocouples were placed in the cheesemaking tank to measure the temperature of the milk gel, one of them in the upper part of the tank, the other — in the lower part. The control of the kinetics of gelation and temperature in different parts of the tank was carried out automatically, while recording the results of observations with an interval of 2 seconds.

Changes occurring on the surface of milk in a cheesemaking tank after the addition of an enzyme preparation and before cutting the curd were recorded under oblique illumination using an Epson H285B LCD projector (Japan) as an illuminator and a screen located perpendicular to the reflected light beam. The image obtained on the screen was recorded with a video camera synchronously with the temperature and viscosity of milk in the cheesemaking tank.

A total of 32 commercial cheese productions were analyzed. Statistical processing of the obtained results was carried out in the MS Excel 2010 program, at a significance level of 0.05.

3. Results and discussion

When carrying out long-term research work in the industrial cheesemaking workshop, we noted the distortion of the image of the production ceiling light on the surface of milk in an open cheesemaking tank in the secondary phase of the formation of a milk curd. Figure 1 gives the first photographs of the image of a ceiling light on the surface of milk in the cheesemaking tank in the enzymatic gelation phase. These images served as the basis and starting point for further research.

Figure 1a gives the reflected image of the ceiling light from the surface of milk in the enzymatic phase of gelation; it is actually a mirror image, only slightly blurred due to small foam residues. The dark spots in the photographs are large remnants of milk foam.

After some time, approximately near the gel point of the milk curd, the image of the illuminator is sharply distorted and takes the form presented in Figure 1b. Obviously, such a distortion of the image can occur only with a local deviation of the reflecting surface of the milk curd from flatness. In turn, this means that in the cheesemaking tank there are previously unknown and unexplored internal dynamic processes that violate the integrity of the structure of the milk curd in the tank.

Further observations found that the distortion of the reflected image increases throughout the entire secondary phase of gelation. This means that the ongoing internal local processes lead to the separation of the curd in the cheesemaking tank into separate segments, the boundaries between which become more and more expressed. Figure 1c gives a photograph of the reflected image of the illuminator on the surface of milk in a cheesemaking tank before the curd is ready for cutting.

Investigations have also found that in the secondary phase of gelation on the surface of the milk gel in the cheesemaking tank, a previously undescribed phenomenon of gel self-segmentation is noted. This phenomenon can be seen in an open-type cheesemaking tank under very close watch with the naked eye; however, observations are greatly hampered by the foam on the surface of the milk that forms when it is stirred. Perhaps this is what previously prevented the detection of milk gel self-segmentation.

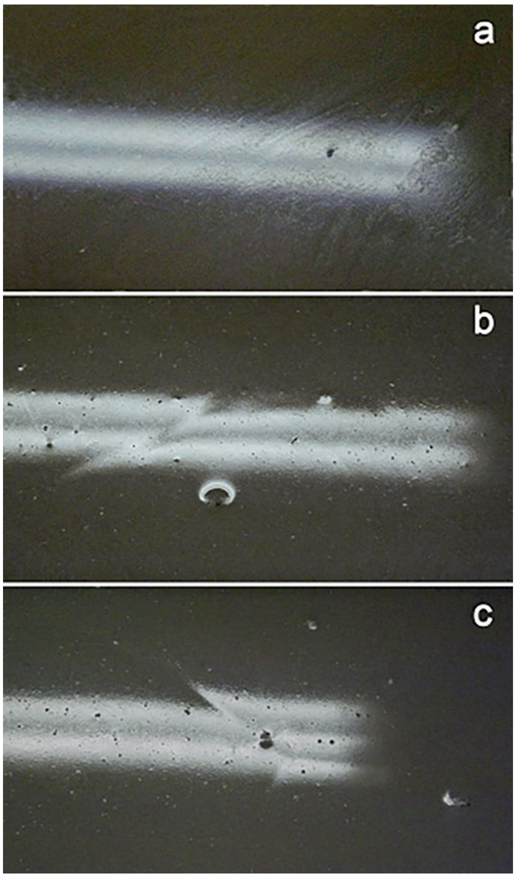

Figure 1. **Image of a ceiling light reflected from the surface of milk in a cheesemaking tank during gelation**

The phenomenon of self-segmentation of the gel is clearly visible under bright oblique illumination of the surface of the milk gel. Under oblique illumination, the reflective surface of milk strongly polarizes the light flux. In the LCD projector we used, the luminous flux from the light source is divided into three color (RGB) components, which pass through their polarizing filters located at different angles. Therefore, by rotating the projector around its optical axis, you can achieve maximum image contrast. In our case, the maximum image contrast was obtained with green light. In addition, the LCD projector makes it possible to form an image of regular bands of a certain width on the gel surface, which is necessary for assessing the size of the resulting segments and their boundaries.

Figure 2 gives photographs of the phenomenon of self-segmentation of a milk curd in a cheesemaking tank, obtained using oblique illumination. Photographs of the surface of the milk curd were taken immediately before the moment of its readiness for cutting. The width of the photos corresponds to the width of the cheesemaking tank — 80 cm.

Externally, Figures 1a and 1b differ significantly, however, these photographs were taken during the development of the same cheese in the same tank, but on different days.

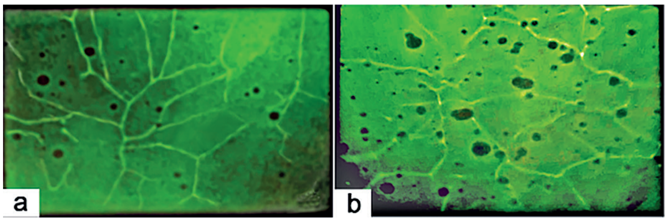

Figure 2. **Photographs of self-segmentation of a milk curd in a cheesemaking tank**

Self-segmentation of milk gel was repeatedly observed by us in the same cheesemaking tank and in different tanks and during the manufacture of different cheeses. At the same time, the shape of the segments and their sizes did not repeat, which did not allow us to reveal correlations between the morphology of self-segmentation and the size and shape of tanks, types of cheese, starter and enzymes, etc. Nevertheless, it can be noted that the time characteristics coincide and that the boundaries of the segments usually begin on the walls of the cheesemaking tank and the characteristic sizes of the segments are close.

The height of the displacement of milk curd segments relative to each other, the width and depth of the boundaries between the segments can be estimated using the light section method, which is widely used in the technique of measuring the unevenness of various surfaces [24]. To do this, an image of regular linear stripes of a certain width (raster) was projected onto the surface of a milk gel in a cheesemaking tank using an LCD projector. The displacement of black stripes on surface irregularities gives an idea of their width and depth. Numerical values can be obtained by measuring the surface distortion in fractions of a known black stripe width, taking into account the magnification and angle of the light source relative to the surface.

Figure 3 gives a photograph of the segmented surface of a milk curd in a cheesemaking tank, on which a line raster image is focused. Figure 4 gives an enlarged fragment of a segmented gel. The photographs clearly show that the surface of the milk curd has significant deviations from flatness, especially noticeable at the boundaries of the segments.

The watch on such deviations from flatness suggests that the milk curd in the tank is inhomogeneous in its physical properties. In some places, it can be denser, in others weaker; the ability to syneresis can also be different. Perhaps this does not affect the quality of the finished cheese, but it is also possible that the

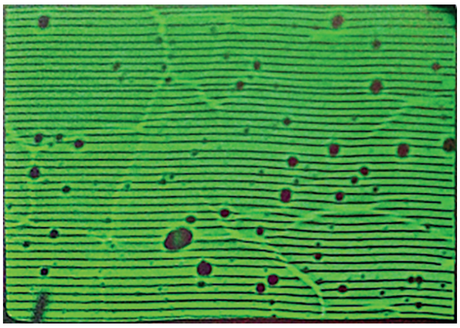

Figure 3. **Image of a segmented milk curd with a raster overlay**

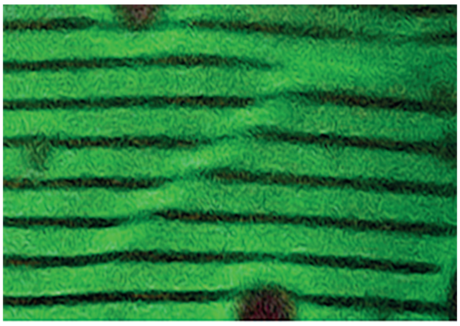

Figure 4. **Enlarged photograph of a segmented milk curd**

segmentation of the curd leads to various defects in the cheese, such as its color, and inhomogeneous texture.

As the photographs show, the border of the transition from one segment to another is smooth and can be convex, stepped or concave. Calculations demonstrate that with a width of images of black stripes on the bunch surface of 2.3 mm, the displacement of the stripes at the boundaries of the segments is from half to two times the width of the strip, the actual displacement of the segments in height is from 0.5 to 2 mm. In our opinion, this is a large value, and the fact that the phenomenon of milk curd self-segmentation was not previously described can be explained by its masking by a layer of foam formed during mixing. The width of the boundary layer between the gel segments increases during gelation from 3 to 10 mm.

The discovered phenomenon of milk gel self-segmentation primarily requires the resolution of two main questions: what causes self-segmentation and what is the practical significance of this phenomenon.

There may be several reasons causing self-segmentation of the gel during its formation. However, in our opinion, one of the main reasons is the thermal convection of the milk in the tank. To test this hypothesis, some studies of the thermodynamics of gelation in a cheesemaking tank were carried out.

Figure 5 gives the results of synchronous registration of changes in temperature and viscosity of the milk gel after the addition of the enzyme preparation. The results presented in Figure 5a were obtained with all three temperature sensors located in the middle of the cheesemaking tank at medium milk depth. Here, the nature of the change in the temperature of the milk gel, recorded by three closely spaced sensors, is the same, but one of the sensors has a systematic error caused by a calibration error. As can be seen from the graph, all three sensors simultaneously register a sharp stabilization of the milk temperature in the middle part of the tank after the gel point. If before the gel point the temperature of the milk in the bath gradually decreased due to natural cooling, then after the gel point it stabilized, which is evidently due to a significant

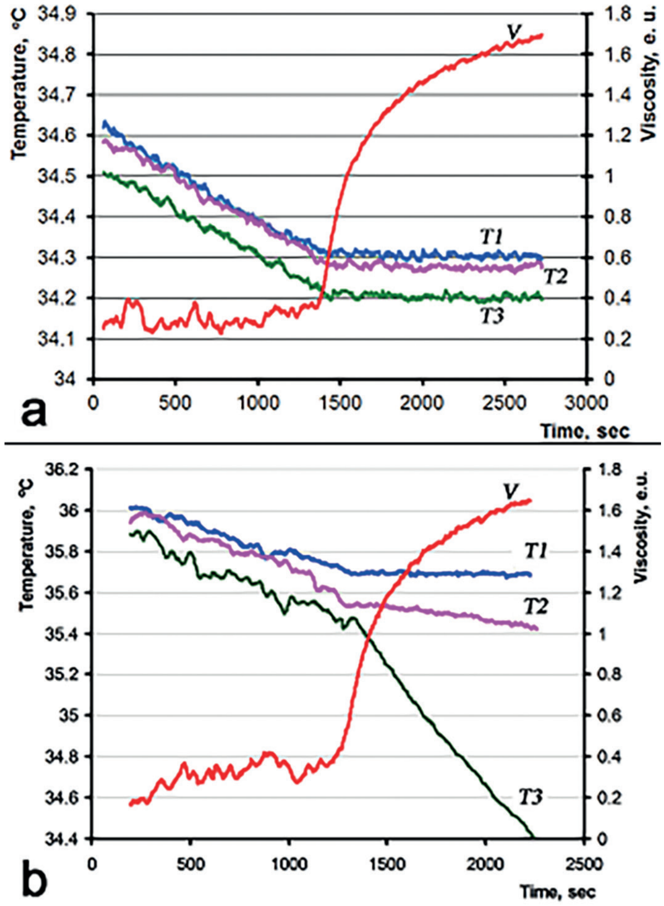

Figure 5. **Changes in milk gel temperature in a cheesemaking tank**

decrease in the thermal conductivity of the milk curd compared to milk.

Viscosity changes up to the gel point have significant spontaneous fluctuations in the region of the enzymatic phase, decreasing with time. Comparison of these fluctuations with synchronous video recording of phenomena on the surface of milk in the tank allows us to conclude that these fluctuations are caused by damped residual flows of milk after stopping the stirrer, which was working when the enzyme preparation was added. It should be noted here that the existence of residual flows and their role in the enzymatic phase of gelation is not taken into account in any way in the known models of the mechanism of gelation.

In the next experiment, changes in the temperature of milk in depth during gelation were carried out using three temperature sensors located at different heights along the same vertical in the middle part of the tank. One of them (*T1*, Figure 5b) was located at the average depth of milk in the tank, the second (*T2*) was in the depth of milk at a distance of 5 cm from the bottom of the tank, and the third (*T3*) at a depth of 5 cm from the surface of the milk. At the same time, using a Hot-Wire sensor, the change in viscosity (*V*) of the milk gel was recorded.

The obtained results show that in the primary enzymatic phase of gelation, there are practically no differences in the nature of temperature changes along the depth of milk. However, in the secondary phase of gelation, temperature changes along the depth of milk differ significantly. At the middle depth, the temperature of the milk is the highest and remains unchanged throughout this phase. Near the bottom of the tank, the temperature of milk is somewhat lower and slowly decreases, and near the surface, the temperature of milk is even lower than near the bottom and decreases much faster. Thus, the cooling of the milk gel in the tank occurs both from below and from above, but more intensively from above. Obviously, these vertical temperature gradients in the cheesemaking tank cause convective movement of the milk as a whole and its components individually. As is known, convective flows coordinated within a certain volume can form Benard convection cells [25]. Cooling on the open surface of the cheesemaking tank, and hence the denser layers of milk fall down, and the warmer inner layers rise up. In our case, this temperature difference is small and, as follows from Figure 5, it is at the moment when the boundaries of the segments appear, i. e. close to the gel point, about 0.2 °C.

Stationary Benard convection cells are dissipative structures. Unlike equilibrium structures, dissipative structures are formed and preserved due to the exchange of energy and matter under nonequilibrium conditions. In known models, it is assumed that the kinematic viscosity and thermal diffusivity of the liquid are constant over time, and change only under the influence of temperature. In addition, it is expected that the liquid is homogeneous. In the case of enzymatic gelation in milk, the viscosity and thermal diffusivity change significantly not only with temperature, but also with time. It is especially important that milk is a complex heterogeneous system, the individual components of which have their own temperature-dependent parameters. For example, milk fat globules have positive buoyancy and a higher coefficient of volumetric expansion compared to other milk components, which, in the case of a temperature gradient, ensures their priority in organizing the convective movements of the liquid.

Evidently, the main factor in the occurrence of convective currents is the presence of a temperature gradient. As the graphs in Figure 5 show, near the time of the gel point, i. e. at the moment when the beginning of self-segmentation is observed, the milk temperatures are low at the bottom of the tank and on the surface, and the highest milk temperature is at an average depth. That is, in the upper part of the open-type tank, during the milk gelation, a negative temperature gradient ΔT occurs (Figure 6), which causes the emergence of circulating convection cells.

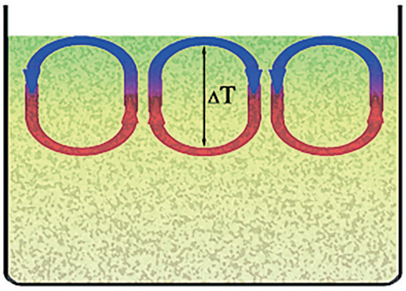

Figure 6. **Benard circulating cells in a cheesemaking tank**

At the same time, there is a positive temperature gradient in the lower part of the tank. This situation is also different from the conditions for the occurrence of Benard convection cells, where it is assumed that heating occurs from the lower side and cooling from the upper side. Therefore, it can be expected that the existence of a two-level self-segmentation of the gel in a cheesemaking tank is also possible, but of a different type.

In general, the mechanism of milk gel self-segmentation in an open-type cheesemaking tank can be as follows. After adding rennet to the milk heated to the required temperature and thoroughly mixing it, hydrolysis of kappa-casein occurs. In the enzymatic phase of milk gelation, damped residual flows remain after intensive mixing. By the end of the fermentation phase, the milk in the tank is partially and unevenly cooled so that vertical temperature gradients are formed in it. When the state of milk approaches the gel point, loose aggregates (flakes) of destabilized paracasein micelles are formed in it. By this point in time, the temperature gradients in the tank reach a threshold value at which milk fat globules, which have a coefficient of thermal volume expansion significantly greater than the surrounding whey, begin to float actively. The floating-up of fat globules is initiated by the action of fluctuations of residual flows after mixing in places with the highest temperature gradient and is accompanied by the fact that fat globules carry along the flakes of paracasein micelles formed by this time. Reaching the surface, warmer volumes of liquid have a lower surface tension there and therefore spread over the surface. That particular process is observed during the expansion of segments on the surface of milk. The process of segment expansion ends when the dissipation of energy due to the increase in the viscosity of the gel exceeds the energy created by the lifting forces. After this, the gel is compacted, but its properties inside the segments and at its boundaries will be different.

Segments in the milk curd do not have a definite regular shape, their average size varies from 5 to 50 cm. Based on the proposed mechanism, the size and shape of the segments should depend on the state of the environment and the design of the cheesemaking tank.

Apparently, with a larger number of segments in the cheesemaking tank, the inhomogeneity of the milk curd in terms of its modulus of elasticity in the volume of the tank is greater, i. e. more difficult is the setting of grain and a greater spread of cheese grain in terms of its physical and chemical properties. The appearance of unacceptable color defects in the finished cheese in the form of spots and nonuniform color, as well as defects in the texture of the cheese is possible as well.

4. Conclusion

Comprehensive studies of the kinetics of gelation, temperature gradients in the cheesemaking tank and changes in the optical and geometric characteristics of the milk surface in the tank made it possible to identify and describe the phenomenon of milk gel self-segmentation.

A description of a possible mechanism of milk gel self-segmentation in open-type cheesemaking tanks based on the formation of Benard convection cells and the effective role of fat globules in this mechanism is proposed.

The research results show that self-segmentation of milk gel in a cheesemaking tank can lead to texture and color defects in the finished product, which requires further research.

REFERENSES

1. Lucey, J. A. (2020). Milk protein gels. Chapter in a book: *Milk proteins: From expression to food.* Oxford: Academic Press. https://doi.org/10.1016/B978–0–12–815251–5.00016–5
2. Fox, P. F., Guinee, T. P., Cogan, T. M., McSweeney P. L. H. (2017). Fundamentals of cheese science. Springer, New York, 2017.
3. Dalgleish, D. G. (1993). The enzymatic coagulation of milk. Chapter in a book: Fox, P. F., (Ed.), *Cheese: Chemistry, Physics and Microbiology, Vol 1,* (2nd edn. pp. 69–100) Chapman & Hall, London. https://doi.org/10.1007/978–1–4615–2650–6_3
4. Hyslop, D. B. (2003). Enzymatic coagulation of milk. Chapter in a book: Fox, P. F., McSweeney, P. L. H. (Eds.), *Advanced Dairy Chemistry, Vol. 1, Part B, Proteins*, (3rd edn., pp. 839–878). Kluwer Academic — Plenum Publishers, New York. https://doi.org/10.1007/978–1–4419–8602–3_24
5. Fox, P F, Guinee, T P. (2013). Cheese science and technology. Chapter in a book: Y. W. Park., G. F. W. Haenlein (Eds). *Milk and dairy products in human nutrition: Production, Composition and Health.* Wiley Blackwell, Oxford. https://doi.org/10.1002/9781118534168.ch17

6. Smykov, I. T. (2015). Kinetics of milk gelation. Part I. Coagulation mechanism. Chapter in a book: *Rheology: Principles, Applications and Environmental Impacts*. New York, NY: Nova Science Publications, 2015.
7. Arai, M., Kuwajima, K. (2000). Role of the molten globule state in protein folding. *Advanced Protein Chemistry,* 53, 209–282. https://doi.org/10.1016/s0065–3233(00)53005–8
8. Surkov, B. A., Klimovskii, I. I., Krayushkin, V. A. (1982). Turbidimetric study of kinetics and mechanism of milk clotting by rennet. *Milchwissenschaft, 37*, 393–395.
9. Farrel, Jr. H. M., Qi, P.X., Brown, E. M., Cooke, P. H., Tunick, M. H., Wickham, E. D. et al. (2002). Molten globule structures in milk proteins: Implications for potential new structure-function relationships. *Journal of Dairy Science*, 85(3), 459–471. https://doi.org/10.3168/jds.S0022–0302(02)74096–4
10. Green, M. L, Grandison, A. S. (1993). Secondary (non-enzymatic) phase of rennet coagulation and postcoagulation phenomena. Chapter in a book: Fox, P. F. (Ed.), *Cheese: Chemistry, Physics and Microbiology, Vol. 1, General Aspects.* (pp. 101–140) Elsevier Applied Science, New York. https://doi.org/10.1007/978–1–4615–2650–6_4
11. Tuszynski, W. B. (1971). A kinetic model of the clotting of casein by rennet. *Journal of Dairy Research, 3*, 115–125.
12. Witten, T. A. Meakin, P. (1983). Diffusion-limited aggregation at multiple growth sites. *Physical Review A,* 28(10), 5632–5642. https://doi.org/10.1103/PhysRevB.28.5632
13. De Kruif, C. G., Holt, C. (2003). Casein micelle structure, functions and interactions. Chapter in a book: Fox, P. F., McSweeney, P. L. H. (Eds.), *Advanced Dairy Chemistry, Vol. 1, Part B, Proteins*, (3rd edn., pp. 233–276). Kluwer Academic — Plenum Publishers, New York.
14. Drake, M. A., Delahunty, C. M. (2017). Sensory Character of Cheese and Its Evaluation. Chapter in a book: P. L. H. McSweeney, P. F. Fox, P. D. Cotter, D. W. Everett (Eds), *Cheese. Chemistry, Physics and Microbiology,* (2nd edn., pp. 517–545). Springer Nature Switzerland AG. https://doi.org/10.1016/b978–0–12–417012–4.00020-x
15. Biango-Daniels, M. N., Wolfe, B. E. (2021). American artisan cheese quality and spoilage: A survey of cheesemakers' concerns and needs. *Journal of Dairy Science,* 104(5), 6283–6294. https://doi.org/10.3168/jds.2020–19345
16. Tunick, M. (2016). **Texture. Chapter in a book:** The Oxford Companion to Cheese, C. W. Donnelly (Ed.), Oxford University Press pp. 708–709.
17. Muthukumarappan, K., Karunanithy, C. (2021). Texture. Chapter in a book: *Handbook of Dairy Foods Analysis.* F. Toldrá, L. M. L. Nollet (Eds.), (2nd ed.). CRC Press Boca Raton. https://doi.org/10.1201/9780429342967
18. Ong, L., Li, X., Ong, A., Gras, S. L. (2022). New Insights into Cheese Microstructure. *Annual Review of Food Science*, 13, 89–115. https://doi.org/10.1146/annurev-food-032519–051812
19. Danev, A., Bosakova-Ardenska, A., Boyanova, P., Panayotov, P., Kostadinova-Georgieva, L. (2019). *Cheese quality evaluation by image segmentation. Proceedings of the 20th International Conference on Computer Systems and Technologies* — CompSysTech'19. https://doi.org/10.1145/3345252.3345258
20. Hori, T. (1985). Objective measurements of the process of curd formation during rennet treatment of milks by the hot wire method. *Journal of Food Science,* 50(4), 911–917. https://doi.org/10.1111/j.1365–2621.1985.tb12978.x
21. Goncalves, B.J., Pereira, C. G, Lago, A. M. T., Goncalves, C. S., Giarola, T. M. O., Abreu, L. R. et al. (2017). Thermal conductivity as influenced by the temperature and apparent viscosity of dairy products. *Journal of Dairy Science,* 100(5), 3513–3525. https://doi.org/10.3168/jds.2016–12051
22. Miyawaki, O., Akalke, S., Yano, T., Ito, K., Saeki, Y. (1993). Shielded hot-wire viscosity sensor on-line for a flowing system using a shield of high thermal conductivity. *Bioscience, Biotechnology, and Biochemistry,* 57, 1816–1819. https://doi.org/10.1271/bbb.57.1816
23. Smykov, I.T. (2018). Milk curd cutting time determination in cheesemaking. *Food systems*, 1(2), 12–20. https://doi.org/10.21323/2618–9771–2018–1–2–12–20 (In Russian)
24. Dennig, D., Bureick, J., Link, J., Diener, D., Hesse, C., Neumann, I. (2017). Comprehensive and highly accurate measurements of crane runways, profiles and fastenings. *Sensors,* 17(5), Article 1118. https://doi.org/10.3390/s17051118
25. Benard, H. (1901). Cell vortices in a liquid web. Optical methods of observation and recording. *Journal of Physics: Theories and Applications,* 10(1), 254–266. https://doi.org/10.1051/jphystap:0190100100025400 (In French)

AUTHOR INFORMATION	СВЕДЕНИЯ ОБ АВТОРАХ
Affiliation	**Принадлежность к организации**
Igor T. Smykov, Doctor of Technical Sciences, Chief Researcher, Department of Physical Chemisry, All-Russian Scientific Research Institute of Butter- and Cheesemaking 19, Krasnoarmeysky Boulevard, Uglich, 152613, Yaroslavl Region, Russia Tel.: +7–48532–9–81–21 E-mail: i_smykov@mail.ru ORCID: https://orcid.org/0000–0002–5663–3662	**Смыков Игорь Тимофеевич** — доктор технических наук, главный научный сотрудник, Отдел физической химии, Всероссийский научно-исследовательский институт маслоделия и сыроделия 152613, Ярославская область, г. Углич, Красноармейский бульвар, 19 Тел.: +7–48532–9–81–21 E-mail: i_smykov@mail.ru ORCID: https://orcid.org/0000–0002–5663–3662
Contribution	**Критерии авторства**
Completely prepared the manuscript and is responsible for plagiarism	Автор самостоятельно подготовил рукопись и несет ответственность за плагиат
Conflict of interest	**Конфликт интересов**
The author declares no conflict of interest.	Автор заявляет об отсутствии конфликта интересов