ODREĐIVANJE OPTIMALNIH PARAMETARA GRANIČNOG SLOJA STRUJE VLAŽNOG VAZDUHA MERODAVNOG ZA INICIJALNI PERIOD KONTINUALNOG PROCESA FORMIRANJA KAJMAKA

DETERMINATION OF OPTIMAL PARAMETERS OF THE MOIST AIR BOUNDARY LAYER FLOW RELEVANT FOR THE INITIAL PERIOD OF CONTINUAL PROCESS OF KAJMAK FORMATION

Olivera EĆIM-ĐURIĆ,
nera@agrif.bg.ac.rs,
Mira RADOVANOVIĆ,
radovanovic.mira@gmail.com,
Aleksandar NEDELJKOVIĆ
nedeljkovicaleksandar@yahoo.com,
Jelena MIOČINOVIĆ,
jmiocin@agrif.bg.ac.rs,
PREDRAG PUĐA
University of Belgrade, Faculty of Agriculture,
pudja@yahoo.com,

Parametri struje vlažnog vazduha pomoću koje se obavlja proces formiranja graničnog sloja na površini mleka predstavljaju značajan faktor u procesu nastajanja kajmaka. Tom prilikom odvija se složeni mehanizam prenosa toplote i materije između mleka i vazduha, koji se realizuje kroz barijeru (pokožicu) promenljive debljine i strukture, formirane tokom procesa. Eksperimentalno je utvrđeno da variranjem relativne vlažnosti vazduha (50-90%), odnosno temperature (20-40^{o}C) dolazi do promene u sastavu i debljini formirane barijere, a time i u njenoj poroznosti. Pri graničnim vrednostima relativne vlažnosti, odnosno temperature ustanovljeno je smanjenje prinosa pokožice. Cilj ovog rada je utvrđivanje optimalnih parametara struje vlažnog vazduha izvođenjem serije merenja u početnoj fazi formiranja kajmaka s ciljem postizanja optimalnog sastava, strukture i prinosa pokožice. Rezultati istraživanja ukazuju da je u proizvodnji kajmaka upravljanje parametrima vlažnog vazduha krucijalni faktor za postizanje visokog kvaliteta i maksimalnog prinosa gotovog proizvoda.

Ključne reči: *vlažan vazduh, prenos materije i toplote, pokožica, kajmak*

Parameters of the moist air stream, by which the boundary layer on the surface of heated milk is formed, have significant impact on the process of kajmak formation. During that process a complex mechanism of heat and mass transfer between moist air and milk takes place through the barrier (a skin layer formed on the milk surface) of variable thickness and structure. Experimentally it was found that with variation of relative humidity (50-90 %) and temperature (20-40^{o}C) a change took place in composition and thickness of the formed barrier and thus in its porosity. It was found that the yield of the formed skin layer was decreased when marginal values of relative humidity and temperature of the moist air were applied. The aim of this study is to determine the optimal parameters of moist air by performing a series of measurements in the initial stage of kajmak formation process, in order to get desired composition and structure of the final product and the high yield of production. The research results indicate that the control of moist air parameters in the kajmak production is the crucial factor for achieving high quality of the final product and maximum yield.

Key words: *moist air, heat and mass transfer, skin layer, kajmak;*

I. Introduction

The initial phase of kajmak formation, i.e. formation of the skin layer on milk surface, takes place as a result of combined effects of: (i) surface phenomena, where compounds with high surface activity are concentrated on the milk/air interface, and (ii) intensive water evaporation due to high milk temperature. Factors that strongly influence the initial phase of kajmak formation process are milk temperature, thermodynamic parameters of moist air and the composition of the starting raw materials [1].

The skin layer formation, i.e. hardening of the surface layer of hot milk, occurs at the moment of reaching the critical concentration of proteins at which they lose their solubility, causing its gelification [2,3], having also a fat concentrated at the interface as a part of a solidized layer. The solid layer formed at milk surface is getting harder and more dried caused by further moisture evaporation. The skin layer usually contains 50-60% fat, about 10% proteins and 30-40% moisture [4,5,6]. During the whole process of kajmak formation, the initially formed skin layer is getting ticker and richer, particularly with fat, yielding the final structure and composition of the product.

All thermodynamic processes that occur during kajmak production are related to the parameters of moist air, taking place at the milk-air interface. During the entire process of kajmak formation, air is in the direct contact with the milk surface and later on with surface of the formed skin layer. One can say that this is an interactive relationship that lasts during the entire process of the kajmak formation, with the most dynamic character during the initial part of skin layer formation. In this regard, the definition of the parameters of the moist air that acts as a working fluid in the process is one of the central issues that need to be considered in the industrialization of kajmak production.

The aim of this study is to determine the optimal parameters of moist air (temperature and relative humidity) in order to achieve maximum yield per unit area of milk and optimal product quality.

II. Material and method

The preparation of milk samples was conducted in accordance with the procedure given by Radovanovic [7]. The exposure of heated milk to the moist air flow was carried out in the dedicated installation at the Laboratory of Thermodynamics and Thermal Engineering of the Faculty of Agriculture, the University of Belgrade [7,8]. The measurement of milk temperature as well as of the vessel wall was performed with a digital thermometer peak Tech 5110/5115 (Germany), thermodynamic parameters and velocity were measured using a Kestrel 4000 NK Instruments (USA). Air velocity in the installation in all experiments was kept constant (0.7m/s). By varying the parameters of moist air (Table 1) five experiments were defined.

Table 1. Moist air status parameters at the entry into the working section of the cooling tunnel

Trial	t [ºC]	φ [%]
D1	30	50
D2	30	70
D3	30	90
D4	40	70
D5	20	70

The measurements were performed with a frequency of 20s during the period of 3600s. For the determination of the composition and yield of skin layer, the following methods were used:

Determination of total solids, ISO 5534:2004 (IDF 4:2004)

Cheese - Determination of fat content, Van Gulik method ISO 3433:2008 (IDF 222:2008)[10];

Milk and milk products - Determination of nitrogen content ISO 8968-1-2014 (IDF 20-1:2014) [11];

Determination of the yield was measured according to the procedure [5];

III. Results and discussion

Based on the defined parameters of moist air, given in Table 1, a series of experiments was carried out in which temperature measurements of moist air, milk and container walls at given measuring positions [1] certain values of exchange heat flux, evaporated water from the milk into the moist air stream, air relative humidity, as well as composition of skin formed were determined. The measured temperature values in the boundary layer of air just above the vessel during the hot phase of kajmak formation process (1 hour) are shown in Figure 1.

The data presented on Figure 2 show that when the value of the inlet temperature of moist air on the inlet to the workspace of the cooling tunnel is 30 °C (experiment D2), a decrease in temperature has relatively low slope, resulting in moderate changes in milk temperature. The expected milk temperature distribution for the minimum and maximum temperature of inlet air were obtained in experiments D4 and D5.

In the case of lower values of inlet air temperature (D5), much faster decrease of air temperature over the milk surface took place, which in turn caused quicker convective cooling of milk.

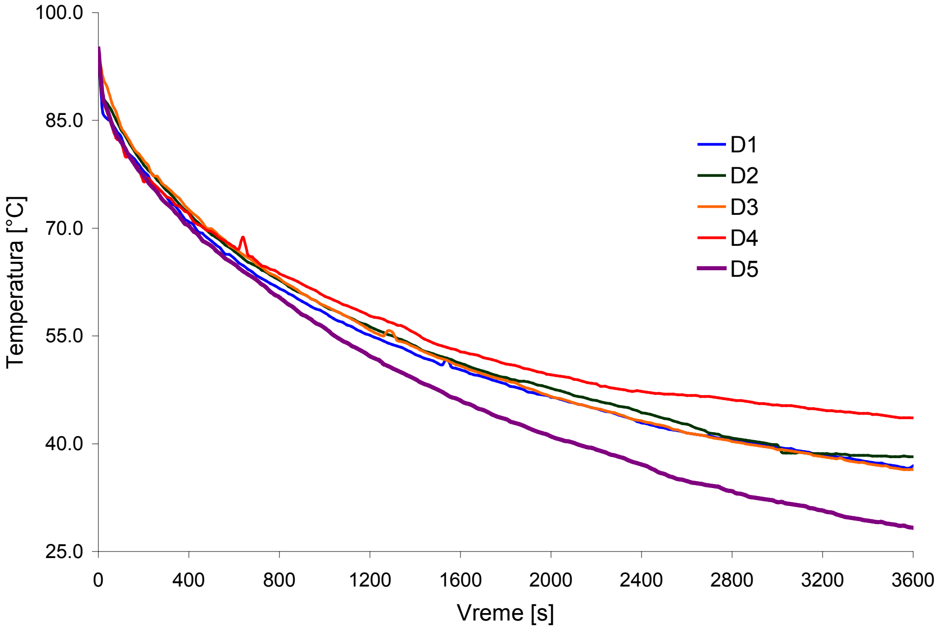

Figure 1. Moist air temperature distibution in the air boundary layer above the milk container

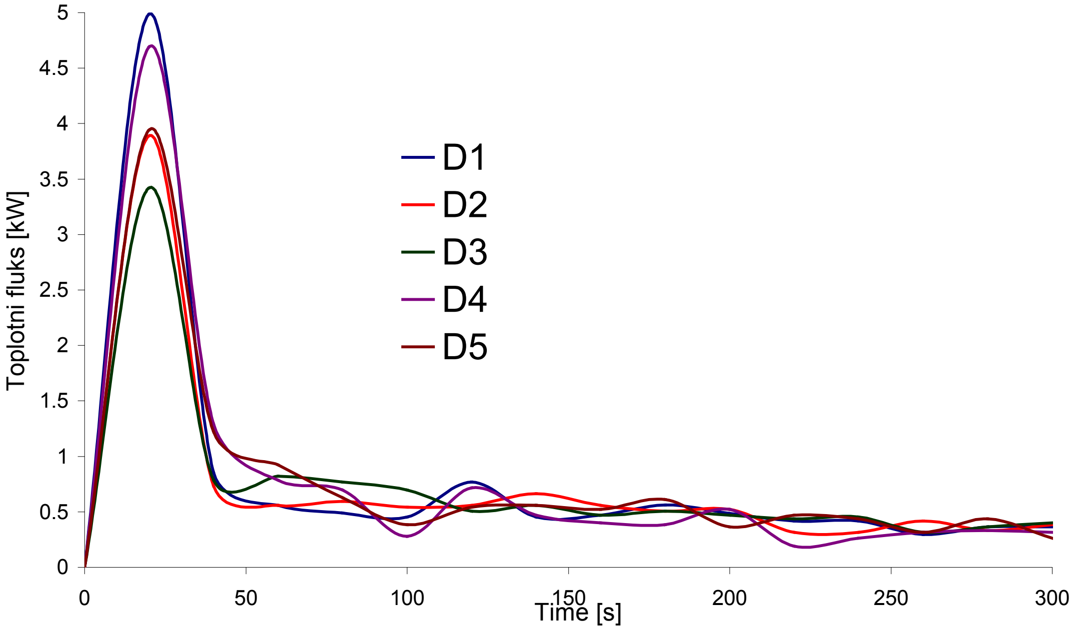

Figure 2. The total heat flux exchanged between milk and moist air during the first 300s of processes

Figure 2 shows the values of the disclosed heat flux from the side of the milk to a stream of moist air during the first 300s of the skin layer formation process. By observing the heat flux of all samples that taken over the time, we can see very unstable dynamics of the total heat disclose from milk to the moist air stream at the very beginning of the process. This can be explained by currently variable parameters of moist air, as well as by strong velocity variations of the local moist air around the vessel with milk. After the formation of the initial skin layer, when the process of heat transfer from the side of milk obtained a predominantly convective nature, the heat exchange becomes much more moderate. From that moment, for all samples, a uniform character of the heat flux exchange is established, which can be described as a predominantly convective heat transfer, that is close to a stationary process. It may also be noted that in trial D2 the heat flux exchange has the most uniform character, which somehow confirms that the chosen parameters for trial D2 act as the optimal for continuous cooling of milk.

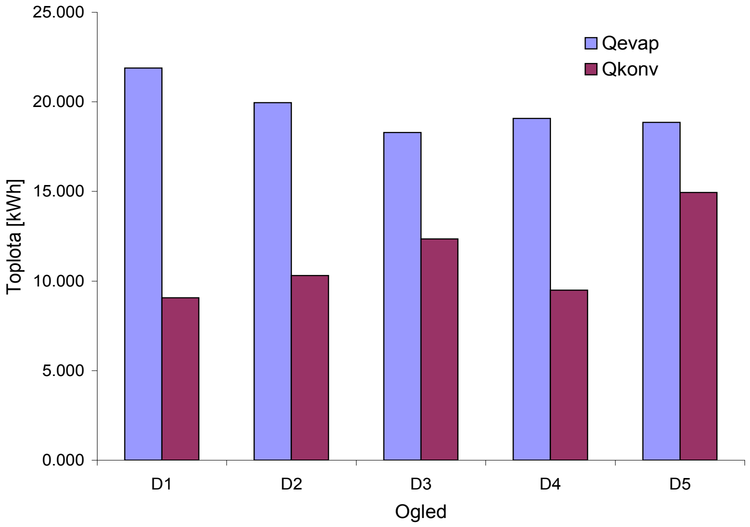

Figure 3. The values of the heat exchanged in all experiments during the period of 3600s

Figure 3 shows the total amount of heat exchanged in all experiments. From Figure 3 it can be seen that in case of the sample D5, where the lowest temperature of moist air was used for flow through the work area of the cooling tunnel, the highest amount of heat was taken. As it was expected, a convective flux was most evident. By comparing experiments D1, D2 and D3, it can be seen that when the air relative humidity is increased, the proportion of convective heat output from the vessel walls to the surrounding air was increased, while the portion of evaporative cooling was decreased. This can be explained as a consequence of lowering the capacity of air to absorb moisture. For samples D2, D4, D5, where air temperature was changed (20-40◦C) and relative humidity was kept constant (30%), it was concluded that the air temperature is not the only influential factor of evaporative heat output. In fact, for the air temperature rise from 20˚C to 30˚C an increase in evaporative cooling was noticed, while further increase in temperature up to 40°C leads to significant decrease of evaporative cooling. An apparently unexpected drop in evaporative cooling that happens when air temperature reaches its highest value, can be explained by the increased barrier influence of the skin layer, which dries rapidly, causing porosity reduction, which in turn results in the slowing down of mass transport through the skin layer.

A confirmation of the air temperature influence on the character of the skin layer can be seen from the analysis of the data of the skin layer yield and composition (Tables 2 and 3). The skin layer yield of the sample D2 was higher than the yields of the rest of skin layers that were taken from samples where the variations of both temperature and relative humidity were applied. The described phenomenon indicates that the parameters of the moist air that are selected in the sample D2 promote better efficiency in the kajmak formation calculated per unit area. The data on dry matter of the skin layer samples showed that the sample D2 is positioned as optimal compared to samples in which both relative humidity and temperature of the air were varied.

Table 2. Yield and composition of skin layer samples in relation to moist air temperature at 70% relative humidity

Trial	Yeald [g]				Composition [%]		
	Skin layer	Fat	Proteins	DM	Fat	Proteins	DM
D5	35,67±0,58 a	18,19±0,46 a	3,24±0,05 a	22,80±0,47 a	51,00±0,50 a	9,09±0,02 a	63,91±0,30 a
D2	40,67±2,52 b	22,36±1,18 b	3,38±0,37 b	27,50±1,47 b	55,00±0,50 b	8,31±0,62 a	67,64±0,79 b
D4	38,67±2,08 ab	22,67±0,96 b	3,31±0,10 b	27,09±1,27 b	58,67±1,15 c	8,58±0,21 a	70,08±0,47 c

*Mean values ± standard deviation;

** Values with the same letter in the column do not differ statistically on significance level p>0,05;

Table 3. Yield and composition of skin layer samples in relation to moist air relative humidity at 30°C

Trial	Yeald [g]				Composition [%]		
	Skin layer	Fat		Skin layer	Fat		Skin layer
D1	31,33±1,15 a	19,22±0,87 a	2,35±0,22 a	22,76±1,13 a	61,33±1,76 a	7,50±0,50 a	72,62±2,26 a
D2	40,67±2,52 b	22,36±1,18 b	3,38±0,37 b	27,50±1,47 b	55,00±0,50 b	8,31±0,62 a	67,64±0,79 b
D3	37,00±1,00 c	20,35±0,64 a	3,31±0,27 b	23,82±0,59 a	55,00±0,87 b	8,93±0,65 a	64,38±0,14 c

*Mean values ± standard deviation;

** Values with the same letter in the column do not differ statistically on significance level p>0,05;

IV. Conclusion

The initial stage of the skin layer formation is characterized by instability in the exchange of heat and mass transfer between milk on cooling and moist air that flows over the milk surface. Yield and composition of the skin layer formed are sensitive to variation of moist air parameters (temperature and relative humidity). These parameters significantly affect the porosity of the skin layer, having a large impact on its composition and properties. The observed variations in the intensity of evaporative cooling indicate changes in the porosity of the formed skin layer. By applying the parameters of moist air in the sample D2 (t =30 ° C, φ= 70%), the most acceptable composition as well as the highest yield of the skin layer was obtained.

ACKNOWLEDGEMENTS

This study is a part of the Project No. 46009 funded by the Ministry of Education, Science and Technological Development, Serbia and FP7 Project AREA No. 316004 funded by EU.

V. Literature

[1] **Radovanović, M., O. Ećim-Đurić, A.Nedeljković, J.Miočinović, P.Puđa,** Analysis of mass and energy balance in the initial stage of kajmak production, *The Proceedings of the 6th Central European Congress on Food, CE Food,* Novi Sad, Srbija, 2012, pp. 1313-1318.

[2] **Nikolai, T.,** *Structure of Self-Assembled Globular Proteins. In "Food Colloids, Self-Assembly and Material Science,* Ed. by Dickinson, E., Leser, M.E. Royal Society of Chemistry, London, UK,2007

[3] **Mahmoudi, N., S.Mahalebi, T. Nicolai, D.Durand, A. Riaublanc,** Light scattering study of the structure of aggregates and gels formed by heat-denatured whey protein isolate and β-lacto globulin at neutral pH. *Journal of Agricultural and Food Chemistry*, 2007, 55, pp. 3104-3111.

[4] **Puđa, P., M. Radovanović, J. Đerovski,** Proizvodnja i svojstva kajmaka, *Mljekarstvo*, 2006, 56 (4), pp. 221-232

[5] **Puđa, P., M. Radovanović, J. Đerovski,** Prilog proučavanju i klasifikaciji kajmaka, *Prehrambena industrija*, 2005, 16, 1-2, pp. 55-60.

[6] **Puđa, P., J. Đerovski, M. Radovanovic,** An autochthonous Serbian product-Kajmak Characteristics and production procedures, *Dairy Science & Technology,* 2008, 88, pp. 163-172.

[7] **Radovanović, M.** *Uticaj sastava i termičkog tretmana mleka na distribuciju proteina u proizvodnji kajmaka i svojstva formirane pokožice*, Doktorska teza, Univerzitet u Beogradu, Beograd, Srbija, 2013.

[8] **Ećim-Đuric, O., M. Radovanović, A. Nedeljkovic, J. Miočinovic, P. Puđa,** Influence of air temperature and relative humidity in the hot phase of kajmak formation, *The First International Symposium on Agricultural Engineering ISAE 2013*, Faculty of Agriculture, Belgrade, 2013, pp IV-65 – V-1,

[9] ***, Cheese and processed cheese – Determination of total solids content ISO 5534:2004 (IDF 4:2004).

[10] ***, Cheese – Determination of fat content – Van Gulik method. ISO 3433:2008 (IDF 222:2008).

[11] ***, Milk and milk products – Determination of nitrogen content – part 1: Kjeldahl principle and crude protein calculation ISO 8968-1-2014 (IDF 20-1:2014).