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O. Hrynchenko<sup>1</sup> – main author, | ©  
A. Borankulova<sup>2</sup>, S. Omelchenko<sup>3</sup>

 <sup>1</sup>Doctor of Technical Sciences, Associate Professor, <sup>2</sup> PhD, Associate Professor  
<sup>3</sup>PhD, Associated Professor  
ORCID <sup>1</sup><https://orcid.org/0000-0002-9867-5502>; <sup>2</sup><https://orcid.org/0000-0002-1229-753X>  
<sup>3</sup><https://orcid.org/0000-0003-3635-6626>  
 <sup>1,3</sup>State Biotechnological University, Kharkiv, Ukraine  
 <sup>2</sup> M.Kh.Dulaty Taraz Regional University, Taraz, Kazakhstan  
@ <sup>1</sup>[grinolny@gmail.com](mailto:grinolny@gmail.com)

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## MECHANISM FOR ADJUSTING THE STRENGTH OF INTERPHASE ADSORPTION LAYERS OF "SKIMMED MILK – SURFACTANT SUBSTANCE" IN DESSERT PRODUCTS

**Abstract.** Today, the range of dessert products produced by the restaurant industry of Ukraine is wide and diverse and is determined by its nomenclature. Mousse is one of the most common dessert dishes ordered in restaurants of various levels. The traditional technological scheme of mousses production is to some extent labor-intensive, and this makes it difficult to satisfy consumer demand. Therefore, the use of a dry mixture in the recipe composition of mousses is justified.

This article is devoted to the investigating the regulatory mechanisms of interphase adsorption layer strength at the interface of the water – oil and water – air phases by introducing surfactants into the dry mixture for the manufacture of dessert products. The choice of surfactants and their concentrations for the formation of interfacial adsorption layers in systems is based on the consideration of surface activity, hydrophilic-lipophilic balance (HLB) and protein concentration, which determines the behavior of the mixture of surfactants in the system. The issue of the influence of surfactants with high and low HLB and their mixtures and the use of a system with three surfactants E472e-E472b-E322, which allow to obtain whipped emulsions from a dry mixture, are considered.

**Keywords:** interphase adsorption layer, surfactants, dry formulation mixture, temperature, ultimate shear stress, ripening.



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**Introduction.** The production of dessert products with a foam emulsion structure with high quality indicators is achieved due to the realization of the functional and technological properties of milk proteins, surfactants, as well as the influence of technological parameters (temperature, maturation time of the foam emulsion system) in order to ensure high foaming capacity, foam stability and product plasticity.

The production of dessert products with a stable foam emulsion structure, with high quality indicators, requires the study of the mechanisms protein and surfactant

dynamics at the water-oil phase and water-air phase boundary at a temperature of  $4 \pm 1$  °C, since protein desorption from the interfacial surface water-oil depends on the concentration and nature of the surfactant (ionic, non-ionic), the amount of HLB, and the decrease in product temperature containing proteins, surfactant blends and simultaneous increase of water-air phase area interface requires determining the role of each component.

The authors of [1] established that lowering the temperature of the emulsion from 20°C to 4°C, which is stabilized by 0.4%  $\beta$ -casein in a composition with surfactants with high HLB (Tween 20) and surfactants with low HLB (mono- and diglycerides) contributed to significant protein desorption from the interfacial surface. The main conclusion of the authors is that a mixture of water- and fat-soluble surfactants promotes more significant protein desorption than each one alone.

It is known from the literature that temperature affects the adsorption and desorption of proteins and surfactants in such systems as milk and cream [2, 3]. Thus, an increase in temperature contributes to an increase in protein adsorption on the interfacial surface and desorption of phospholipids. Decrease in temperature below the melting point of fat leads to desorption of proteins and phospholipids into blood plasma [4], resulting in emulsion destabilization of milk and cream, which causes destabilization of milk and cream emulsion. Mechanical influences also have a significant impact on destabilization such as homogenization and whipping [5, 6].

The purpose of the research is to study the regularities of the formation of interphase adsorption layers (IAL) of model systems on the interface of water-oil, water-air phases at the technological process stages – cooling and whipping, containing dry skimmed milk, surfactants and their mixtures, for substantiation parameters of the technological process of whipped emulsions production from dry mixtures.

The basic components forming the structure of foaming emulsion food products include skimmed milk powder as a source of proteins, surfactants E472e, E472b, E322 and a stabilizer [7].

**Conditions and methods of research.** Determining the ultimate shear stress (USS) of interphase adsorption layers was carried out with the help of a device similar in principle to Rebinder's device. The essence of the method for determining the strength of interphase adsorption layers is to determine the angle of deviation of the glass disc of the device at the interface of the phases.

The ultimate shear stress (USS) of the interfacial adsorption layers (IAL) was determined by the formula:

$$P_s = \frac{C_o \times S_o}{360 \times R_l^2 \times n} \quad (1)$$

where  $P_s$  – the ultimate shear stress of interphase adsorbent layers, N/m;

$C_o$  – modulus of elasticity of the wire, (N×m)/degree;

$S_o$  – deflection of the recorder photocell at the moment of maximum glass disk displacement, m;

$R_l$  – glass disk radius, m;

$n$  – factor for converting angle degrees to scale meters.

To research the USS of IAL in foam emulsion systems, we have proposed a research method that is formed at the interface of the water-air phases in foam emulsion systems. The essence of the method is that two crystallizers connected by a tube were used to study the strength of IAL, a solution of reconstituted milk powder

was poured into one of them, and plant oil was injected onto the surface of the solution. The whole system was incubated for  $2.0 \times 3600$  s at  $20 \pm 1^\circ\text{C}$  to form adsorbent layers at the water-oil interface. Then the test tube valve was opened, the reducing liquid was partially transferred to the second crystallizer and for the formation of layers at the water-air interfaces, it was kept for  $2.0 \times 3600$  s at a temperature of  $4 \pm 1^\circ\text{C}$ , after which the USS of IAL at the water-air phase interface was determined. Lowering the temperature to  $4 \pm 1^\circ\text{C}$  will contribute to the fact that at low temperatures, low-molecular-weight surfactants are more surface-active than proteins, as a result of which the stability of dispersed systems containing proteins and surfactants will change. From a technological point of view, the whipping of dessert products from a dry mixture was carried out at a temperature of  $4 \dots 8^\circ\text{C}$ , this dictated the need to study the behavior of proteins and surfactants at the phase separation in order to determine emulsion behavior in the foaming process.

**Research results and discussion.** To identify the behavior of each surfactant in the formation of foam emulsion systems and their role in the formation of IAL, studies were carried out of the USS of IAL, formed at the phase separation at  $t = 4 \pm 1^\circ\text{C}$  for  $4 \times 3600$  s, that is, time necessary for IAL adsorption and formation as a function of protein participation at the interface of the water-air and water-oil phases.

It has been established that the correlation between IAL USS and skim milk content has an extreme character with a maximal value corresponding to the content of 4.0% skim milk powder and is  $(1.04 \pm 0.05) \times 10^{-3}$  N/m at the water-oil phase interface (Fig. 1, curve  $\diamond$ ) and  $(0.74 \pm 0.03) \times 10^{-3}$  N/m at the water-air phase interface (Fig. 1, curve  $\square$ )

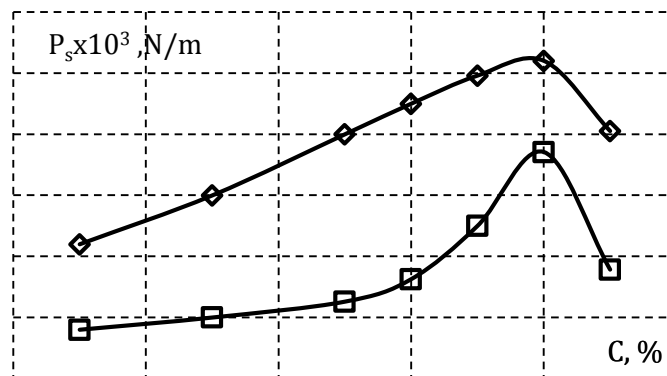


Fig. 1. Dependence of effect of IAL on reduced skim milk content at temperature of  $4 \pm 1^\circ\text{C}$  at the phase interface:  $\diamond$  – water-oil;  $\square$  – water-air

The presence of an extremum on the curves is probably related to the formation of a monomolecular layer.

In order to establish the behavior mechanisms of dairy proteins and surfactants at the interface of water-oil and water-air phases at a temperature of  $4 \pm 1^\circ\text{C}$ , we decided to reduce protein and surfactant concentrations by 10 times, to ensure the preservation of liquid phase separations, since at the content of surfactants 0.2% and above, fat crystallization occurs, and the provision of the condition that the concentration of surfactant is higher than the critical concentration of micelle formation (CCMF) while maintaining protein/surfactant ratio. There will only be a difference in absolute USS values of IAL, but this will make it possible to establish

regularities of system behavior, in particular, at the water-oil interface. In the initial phase of the research, the influence of one surfactant on the USS of IAL at the interface of the water-oil, water-air phases systems "milk – surfactant" were defined to clarify the behavioral mechanisms of each surfactant separately, fixing the content of skimmed milk at the level of 4.0%.

The concentration of E472e surfactant in the "milk - E472e" system was found to increase from 0.02% to 0.08% of the USS of IAL at the water-oil phase interface increases from  $(1.80 \pm 0.09) \times 10^{-3}$  to  $(7.1 \pm 0.3) \times 10^{-3}$  N/m (Fig. 2, curve – □). At the water–air phase interface, a similar dependence was obtained, but with smaller absolute values (Fig. 2, curve – Δ).

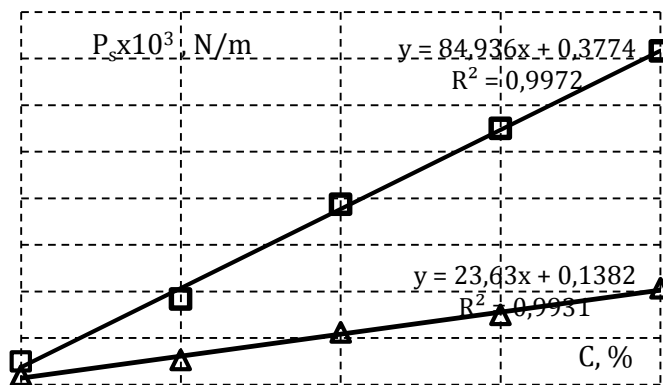


Fig. 2. Dependence of USS of IAL on the concentration of E472e of the "milk-E472e" system at a temperature of  $4 \pm 1^\circ\text{C}$  at the phase interface: □ – water-oil; Δ – water-air

So when concentration of E472e surfactant is raised from 0.02 up to 0.08%, the USS of IAL increases from  $(0.53 \pm 0.02) \times 10^{-3}$  to  $(2.2 \pm 0.1) \times 10^{-3}$  N/m.

The dependence of the USS of IAL on the concentration of E472b surfactant at the interface of the water-oil, water-air phases was identified (Fig. 3).

It was established that the dependence (Fig. 3, curve – □) is extreme with a maximum corresponding to E472b concentrations of 0.04...0.06% and is  $(0.54 \dots 0.58) \times 10^{-3}$ , N/m. A similar dependence derived at the water-air interfacial phase (Fig. 3, curve – Δ). The maximum corresponds to E472b concentrations of 0.04...0.06% and is  $(0.150 \dots 0.165 \pm 0.010) \times 10^{-3}$  N/m. By comparing the absolute data of the USS of IAL of the "milk-E472b" systems and the system containing only reconstituted skimmed milk, it can be asserted that the introduction of E472b helps to reduce the strength of the IAL at the water-air interface, therefore, the IAL durability in the system with 0.35% of skimmed milk is  $(0.193 \pm 0.009) \times 10^{-3}$  N/m. At the interface of the water–oil phases, the strength in the system containing 0.35% skimmed milk is  $(0.50 \pm 0.02) \times 10^{-3}$  N/m, so a slight increase in strength can be achieved only with an E472b content of 0.04 ...0.06%.

The dependence of the USS of IAL on the concentration of surfactant E322 in the "milk-E322" systems was determined (Fig. 4).

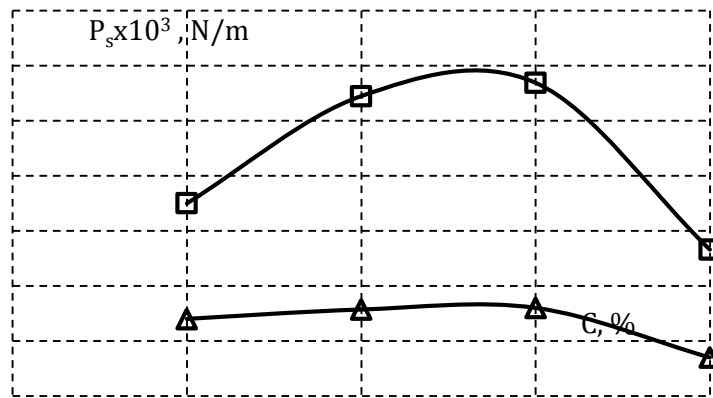


Figure 3. The dependency of USS of IAL on the concentration of E472b of the "milk-E472b" system at a temperature of  $4\pm 1^\circ\text{C}$  at the phase interface: □ – water-oil; Δ – water-air

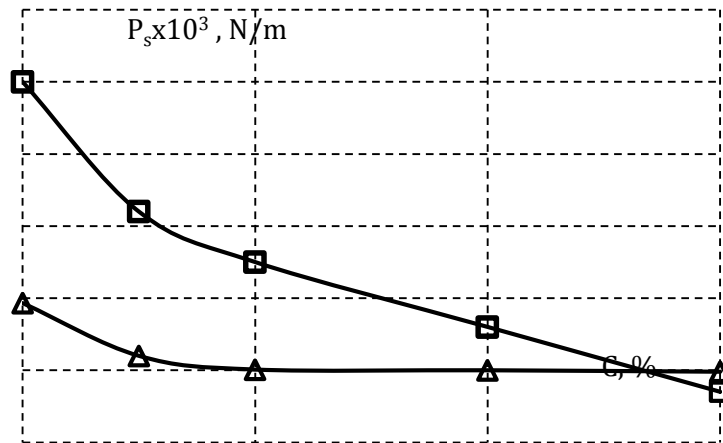


Fig. 4. Dependence of USS of IAL on the concentration of E322 of the "milk-E322" system at a temperature of  $4\pm 1^\circ\text{C}$  at the interface of the phases: □ – water-oil; Δ – water-air

At increase of E322 surfactant concentration with 0.01 to 0.06% in the system "milk - E322" at the interface of water-oil phases it was ascertained that the following results were obtained the USS of IAL decreases from  $(0.340\pm 0.017)\times 10^{-3}$ , N/m to  $(0.070\pm 0.003)\times 10^{-3}$ , N/m (Fig. 4, curve – □), and from  $(0.120\pm 0.006)\times 10^{-3}$ , N/m to  $(0.098\pm 0.004)\times 10^{-3}$ , N/m at the water-air phase interface (Fig. 4, curve – Δ), consequently.

The utilization of two surfactants E472b and E472e was researched to increase the foaming capacity (FC) and foam stability (FS) [7] (Fig. 5).

It was established that in the "milk-E472b-E472e" systems with a low content of E472b of 0.02%, the IAL USS correlation at the water/oil phase boundary has an extremal character with a maximum that corresponds to the E472e content of 0.04%, and amounts to  $(8.00\pm 0.13)\times 10^{-3}$  N/m, i.e. the strength of IAL increases by 22 times (Fig. 5, curve – ◇). By increasing the E472b concentration to 0.04-0.06%, as the E472e content increases, the USS of IAL increases as well. With an E472b content of 0.04%, with an increase in E472e to 0.08% USS of IAL increases to  $(12.0\pm 0.6)\times 10^{-3}$  N/m, i.e. by 23 times (Fig. 5, curve – □). With an E472b content of

0.06%, with an increase in E472e to 0.08% USS of IAL increases to  $(14.3 \pm 0.4) \times 10^{-3}$  N/m, i.e. by 24 times (Fig. 5, curve –  $\Delta$ ).

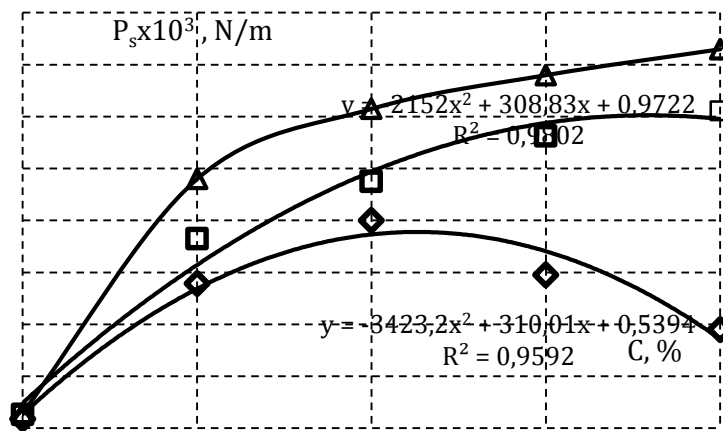


Fig. 5. Dependence of USS of IAL on the concentration of E472e of the "milk-E472b-E472e" system at a temperature of  $4 \pm 1^\circ\text{C}$  at the interface of the water-oil phases with the content of E472b, %:  $\diamond$  – 0.02;  $\square$  – 0.04;  $\Delta$  – 0.06

In the "milk-E472b-E472e" systems at the interface of the water-air phases with an increase in the concentration of surfactant E472e to 0.08%, with an E472b content of 0.04%, the USS of IAL increases (Fig. 6, curve -  $\Delta$ ) to  $(3.00 \pm 0.15) \times 10^{-3}$ , N/m and with the E472b content of 0.06% (Fig. 6, curve -  $\square$ ) increases to  $(3.60 \pm 0.18) \times 10^{-3}$ , N/m i.e. the strength of IAL increases by 20 and 22 times, respectively.

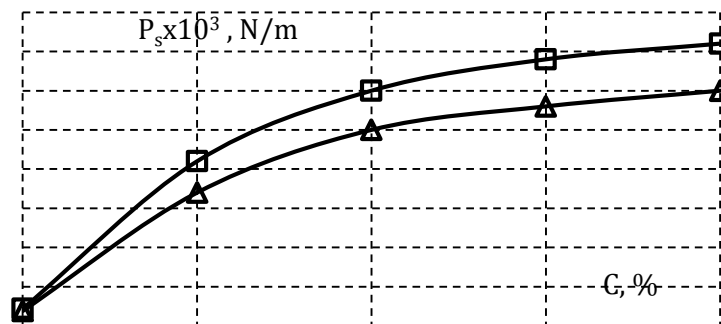


Fig. 6. Dependence of USS of IAL on the concentration of E472e of the "milk-E472b-E472e" system at a temperature of  $4 \pm 1^\circ\text{C}$  at the interface of the water-air phases with the content of E472b:  $\Delta$  – 0.04%;  $\square$  – 0.06%

To verify the participation of all surfactants in forming the interfacial adsorbent interlayers, the CSS of IAL systems "E472b - E472e" were identified. It is revealed that the USS of IAL systems with no dairy proteins are featured less strength approximately 2-3 times (Fig. 7), which confirms the participation of all surfactants in the formation of IAL.

Therefore, by increasing the concentration of E472e surfactant from 0.02 to 0.06% in the "E472b-E472e" system, with an E472b content of 0.04% at the interface of the water-oil phases USS of IAL increases from  $(1.50 \pm 0.07) \times 10^{-3}$  to  $(6.7 \pm 0.3) \times 10^{-3}$  N/m (Fig. 7, curve –  $\square$ ). In water-air phase boundary, with increasing concentration

of E472e surfactant from 0.02 to 0.04% in the E472b-E472e system, the CSS of IAL rises from  $(0.6 \pm 0.03) \times 10^{-3}$  to  $(0.92 \pm 0.04) \times 10^{-3}$  N/m further increase in the concentration of E472e to 0.08% surfactant leads to a decrease of USS of IAL to  $(0.7 \pm 0.03) \times 10^{-3}$  N/m (Fig. 7, curve –  $\Delta$ ). Thus, it can be asserted that in systems containing milk proteins and surfactants with low HLB (E472b) and high HLB (E472e), IAL with high strength indicators are formed, which ensure the stability of emulsions and foams at low temperatures.

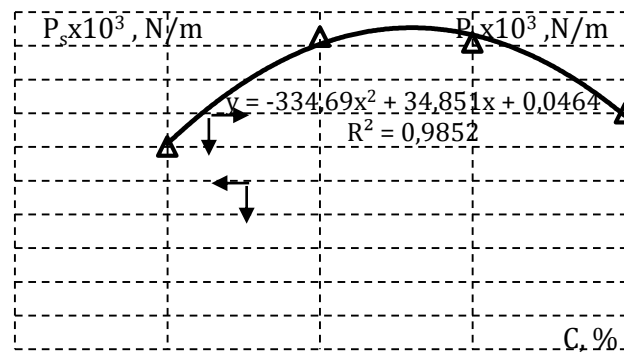


Fig. 7. Dependence of USS of IAL on the concentration of E472e of the "E472b-E472e" system at a temperature of  $4 \pm 1^\circ\text{C}$ , with a content of E472b of 0.04% at the phase interface:  $\square$  – water-oil;  $\Delta$  – water-air

It was established that the introduction of E322 into the "milk-E472e-E472b-E322" system at the interface of the water-oil phases leads to a decrease in the USS of IAL (Fig.8).

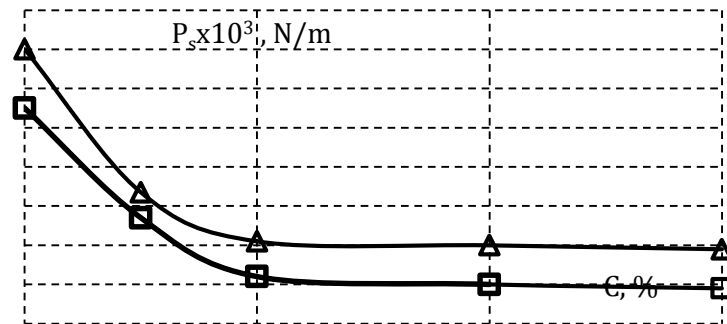


Fig. 8. Dependence of USS of IAL on the concentration of E322 of the system "milk-E472e-E472b-E322" at a temperature of  $4 \pm 1^\circ\text{C}$  at the interface of the water-oil phases by content, %:  $\square$  – E472e 0.06 E472b 0.04;  $\Delta$  – E472e 0.06 E472b 0.06

Thus, with an increase in the concentration of E322 surfactant to 0.06% in the "milk-E472e-E472b-E322" system, with the content of E472e 0.06%, E472b 0.04%, USS of IAL will decrease from  $(11.0 \pm 0.5) \times 10^{-3}$  N/m to  $(1.80 \pm 0.09) \times 10^{-3}$  N/m (Fig. 8, curve –  $\square$ ), i.e., USS of IAL decreases by 2.7 times, which is probably due to desorption of proteins from the interfacial surface, it can be assumed that the desorbed protein within the emulsion system will facilitate its foaming during whipping. With the content of E472e 0.06%, E472b 0.06% (Fig. 8, curve –  $\Delta$ ) the

USS of IAL will decrease from  $(14.0 \pm 0.7) \times 10^{-3}$  N/m to  $(3.80 \pm 0.19) \times 10^{-3}$ , N/m, i.e. the strength of IAL will decrease by 3.6 times.

In order to establish the role of E322 surfactant in the formation of IAL, the effect of E322 on the USS of IAL of "E472e-E472b-E322" systems, that is, systems without milk proteins, was determined (Fig. 9).

The analysis of the obtained data showed that E322 contributes to the reduction of USS of IAL from  $(6.5 \pm 0.3) \times 10^{-3}$  N/m to  $(0.96 \pm 0.02) \times 10^{-3}$ , N/m, i.e. the USS of IAL decreases by 6.5 times. A comparison of the absolute values of the USS of IAL with systems containing milk proteins shows that in the presence of proteins in the system their power is approximately 2 times higher, which allows us to assert that E322 promotes partial desorption of all surfactants involved in forming IAL. (Fig. 9)

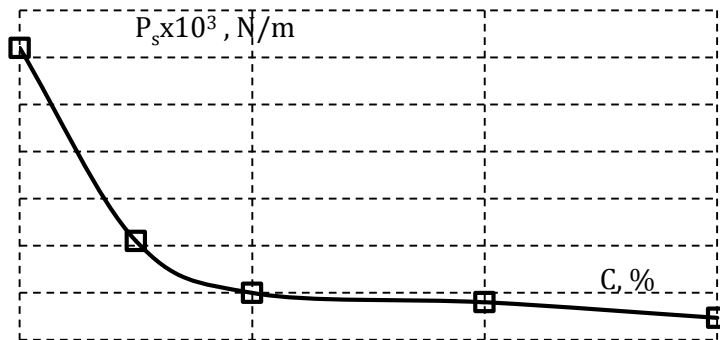


Fig. 9. Dependence of USS of IAL on the concentration of E322 of the system "E472e-E472b-E322" at a temperature of  $4 \pm 1^\circ\text{C}$  at the interface of the water-oil phases by content, %: E472e 0,06 E472b 0,04

It is found that the addition of E322 into the "milk-E472e-E472b-E322" system at the interface of the water-air phases contributes to the increase of the USS of IAL. By comparing the absolute data of the USS of IAL at the interface of the water-oil and water-air phases, it can be seen that at the interface of the water-air phases the USS is 1.3 times higher, which gives grounds for asserting the energy advantage of creating foam in an emulsion system based on a system of four surfactants: milk proteins, E472e, E472b, E322.

Thus, with an increase in the concentration of surfactant E322 to 0.06% in the "milk-E472e-E472b-E322" system, with the content of E472e 0.06%, E472b 0.04%, the USS of IAL will increase from  $(2.7 \pm 0.13) \times 10^{-3}$  N/m to  $(3.01 \pm 0.15) \times 10^{-3}$ , N/m, i.e., the USS of IAL increases by 1.1 times (Fig. 10, curve – □). With the content of E472e 0.06%, E472b 0.06% (Fig. 10, curve – Δ) the USS of IAL will increase from  $(3.2 \pm 0.7) \times 10^{-3}$  N/m to  $(4.1 \pm 0.19) \times 10^{-3}$ , N/m, i.e., the strength of IAL will increase by 1.3 times.

By experimental studies, it was shown that in the system "E472e-E472b-E322" with no dairy proteins at the water-air interface, the interfacial adsorption interlayers are so poorly defined that it was not possible to fix.

The research carried out enables to specify the formation mechanism of interfacial adsorption layers at the boundary of water-oil, water-air interfaces in the systems that contain milk proteins, surfactants and their mixtures at the temperature of  $4^\circ\text{C}$ . Interfacial adsorption layers in systems comprising milk proteins and surfactants with low hydrophilic-lipophilic balance (E472b, E322) are less strong than in systems without surfactants, that is, such surfactants facilitate desorption of



proteins from interfacial area. With high hydrophilic-lipophilic balance (E472e), interfacial adsorption layers with high strength parameters are formed, which will contribute to the stability of emulsions and foams.

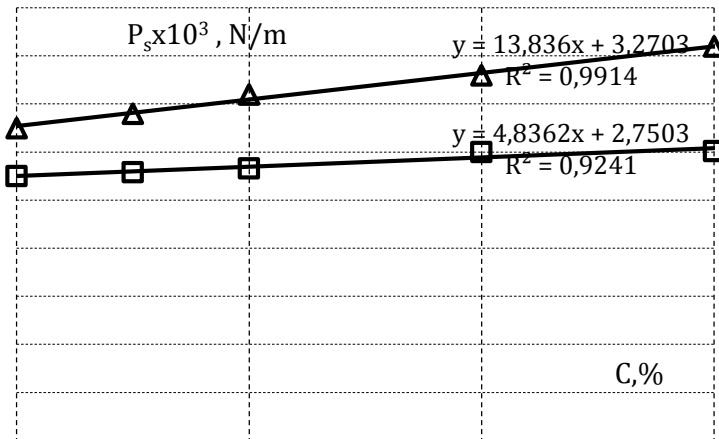


Fig. 10. Dependence of USS of IAL on the concentration of E322 of the system "milk-E472e-E472b-E322" at a temperature of  $4 \pm 1^\circ\text{C}$  at the interface of the water-air phases by content, %: □ – E472e 0,06 E472b 0,04; Δ – E472e 0,06 E472b 0,06

**Conclusion.** Manufacturing the dessert products on the basis of dry mixture with two surfactants with high hydrophilic-lipophilic balance E472e and low hydrophilic-lipophilic balance E472b allows to increase significantly the strength of interfacial adsorption layers by about 20...24 times at the interface of water-oil, water-air phases in comparison with systems without surfactants. Application of a combination of three surfactants E472e, E472b, E322 enables to reach higher strength of interfacial adsorption layers at the interface of water-air phases in comparison with the strength at the interface of water-oil phases, which provides high foaming ability and the stability of dry mixture whipped dessert products.

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**О. Гринченко<sup>1</sup>, А. Боранқұлова<sup>2</sup>, С. Омельченко<sup>1</sup>**

<sup>1</sup>Мемлекеттік технологиялық университет, Харьков қ., Украина

<sup>2</sup>М.Х. Дулати атындағы Тараз өңірлік университеті, Тараз қ., Қазақстан

**ДЕСЕРТ ӨНІМДЕРІНДЕГІ "МАЙЫНАН АЖЫРАТЫЛҒАН СҮТ – БЕТТІК БЕЛСЕНДІ ЗАТТАР" ЖҮЙЕСІНІҢ АДСОРБЦИЯЛЫҚ ФАЗА АРАЛЫҚ ҚАБАТЫНЫҢ БЕРІКТІГІН РЕТТЕУ МЕХАНИЗМІ**

**Аңдатпа.** Бүгінгі таңда Украинаның мейрамхана индустриясы шығаратын десерт өнімдерінің асортименті кең және алуан түрлі және оның номенклатурасымен анықталады. Мусс әртүрлі деңгейдегі мейрамханаларда тапсырыс берілетін ең көп таралған десерт тағамдарының бірі. Мусс өндірісінің дәстүрлі технологиялық схемасы біршама уақытты қажет етеді және бұл тұтынушылардың сұранысын қанағаттандыруды қиындатады. Сондықтан рецепт бойынша мусс құрамындағы құрғақ қоспаны қолдану негізделген.

Бұл мақала десерт өнімдерін өндіру үшін құрғақ қоспаға беттік белсенді заттарды енгізу арқылы су-май және су-ауа фазаларының шекарасындағы фазааралық адсорбциялық қабаттың беріктігін реттеу механизмдерін зерттеуге арналған. Жүйелерде фазааралық адсорбциялық қабаттарды қалыптастыру үшін беттік белсенді заттар мен олардың концентрациясын таңдау беттік белсенділікті, гидрофильді-липофильді тепе-теңдікті (HLB) және жүйедегі беттік белсенді заттар қоспасының әрекетін анықтайтын ақуыз концентрациясын есепке алуға негізделген. Жоғары және төмен HLB беттік белсенді заттардың және олардың қоспаларының әсері, сондай-ақ құрғақ қоспадан көпіршітілген эмульсияларды алуға мүмкіндік беретін үш беттік белсенді зат е472e-E472b-E322 жүйесін пайдалану қарастырылады.

**Тірек сөздер:** фаза аралық адсорбциялық қабат, беттік белсенді заттар, құрғақ рецепт қоспасы, температура, шекті ығысу кернеуі, жетілу.

**О. Гринченко<sup>1</sup>, А. Боранқұлова<sup>2</sup>, С. Омельченко<sup>1</sup>**

<sup>1</sup>Государственный биотехнологический университет, г. Харьков, Украина

<sup>2</sup>Таразский региональный университет им. М. Х. Дулати, г. Тараз, Казахстан

**МЕХАНИЗМ РЕГУЛИРОВАНИЯ ПРОЧНОСТИ МЕЖФАЗНЫХ АДСОРБЦИОННЫХ СЛОЕВ "МОЛОКО ОБЕЗЖИРЕННОЕ – ПОВЕРХНОСТНО-АКТИВНЫЕ ВЕЩЕСТВА" В ДЕСЕРТНОЙ ПРОДУКЦИИ**

**Аннотация.** Сегодня асортимент десертной продукции, производимой ресторанной индустрией Украины, широк и разнообразен и определяется ее номенклатурой. Мусс – одно из самых распространенных десертных блюд, заказываемых в ресторанах различного уровня. Традиционная технологическая схема производства муссов в некоторой степени трудоемка, и это затрудняет удовлетворение потребительского спроса. Поэтому использование сухой смеси в рецептурном составе муссов оправдано.

Данная статья посвящена исследованию механизмов регулирования прочности межфазного адсорбционного слоя на границе раздела фаз вода – масло и вода – воздух путем введения поверхностно-активных веществ в сухую смесь для

производства десертных изделий. Выбор поверхностно-активных веществ и их концентраций для формирования межфазных адсорбционных слоев в системах основан на учете поверхностной активности, гидрофильно-липофильного баланса (HLB) и концентрации белка, которые определяют поведение смеси поверхностно-активных веществ в системе. Рассмотрен вопрос о влиянии поверхностно-активных веществ с высоким и низким HLB и их смесей, а также использование системы с тремя поверхностно-активными веществами E472e-E472b-E322, которые позволяют получать взбитые эмульсии из сухой смеси.

**Ключевые слова:** межфазный адсорбционный слой, поверхностно-активные вещества, сухая рецептурная смесь, температура, предельное напряжение сдвига, созревание.