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MILK AND ITS PROPERTIES AS AN OBJECT OF SEPARATION

Evgeniy Chebotarev[1*], Khazbi Sugarov[1], Andrey Bratsikhin[2]

[1]Engineering Institute, North Caucasus Federal University, Pushkina Street 1, Stavropol, 355009, Russian Federation
[2]Life Sciences Institute, North Caucasus Federal University, Pushkina street 1, Stavropol, 355009, Russian Federation

[*]e-mail: eacheb@mail.ru

Abstract

Separation is one the essential processes in dairy products processing. In the article, properties of milk that are determining the value of milk separability as a disperse system, namely the density of plasma and disperse particles, the viscosity of plasma and disperse structure of disperse phases are considered. Correlation of density and viscosity of the milk components with a temperature is reviewed. Distribution of fat globules in milk, milk-fat globule membrane (MFGM) thickness and influence of mechanical impact (pumping, mixing, centrifugal purification) on disperse structure of fat in milk are also reviewed.

Milk is considered as a low-concentration finely combined (emulsion + suspension) dispersion system. As the separation remains one of the most used method of clarification and purification of milk, it is necessary to know curtain properties of milk components. The efficiency of milk separation process relies on knowledge of such properties, such density and viscosity of milk plasma, density of milk fat globules, thickness of milk fat globule membrane, distribution of fat globules by the size. The ways of calculation of these properties are presented. In addition, mechanical impact on milk properties in the course of its receiving and processing is reviewed. Calculation of separability of disperse systems 'milk fat globule-milk plasma' and 'milk mechanical impurities – milk plasma' is presented.

The separability values of milk fat globules and milk mechanical impurities in dependence on milk temperature, in the range 30 – 70 °C and 5 – 75 °C respectively, are presented in the article and could be used in calculations of separators-clarifiers and separators-purifiers. The properties of separators sludge, which is created in course of whole or skim milk purification, and the sizes of its particles are still to be discovered.

***Key words**: Milk, Milk separability, Milk fat globule, Milk fat globule membrane, Density, Viscosity, Fat globule size distribution.*

1. Introduction

With the development and improvement of the technological processes of separation, it is important to consider the composition and properties of separated products. Separation process is highly dependent on temperature and therefore determination of density, viscosity and size distribution of the milk components with a correlation to temperature is essential in calculation of parameters of this process. In the article, authors review the characteristics of the milk as an object of a centrifugal separation. The key properties from this point of view are: density and viscosity of milk components, particles distribution of disperse structure.

The calculation of numerical values of following characteristics of milk components reviewed in the article are: density and viscosity of milk plasma as a function of temperature, density of milk fat globule and milk fat globule membrane (MFGM) and its dependence on the temperature, quantitative and volume distribution of milk fat globules, influence of mechanical impact on disperse structure of milk.

The knowledge of these characteristics is of particular interest in calculation of a process of milk centrifugal separation, which is carried out by warming up of a product beforehand up to temperature 30 - 45 ^{0}C or even up to higher temperature.

2. Properties of milk as an object of separation

2.1. Milk plasma

Milk is a low-concentration finely combined (emulsion + suspension) dispersion system. The emulsion in milk is formed by fat globules, the suspension is formed by mechanical impurities, coagulated protein particles and microorganisms.

Milk plasma primarily consists of colloidal solution of proteins and molecular and ionic solutions of lactose and mineral salts. These components determine the structural mechanic properties of milk plasma and the dependence of these properties mainly from temperature.

Density and viscosity of milk plasma can be determined accurately by the formulas obtained for skimmed milk [1]:

$$\rho_{pl} = 1037.6 - 0.1395\,t - 0.0033\,t^2 \qquad (1)$$

Where:
ρ_{pl} - Density of milk plasma, kg/m³; t - temperature, °C.

$$\eta_{pl} = 0.037\,t^{-0.92} \qquad (2)$$

Where:
η_{pl} - Viscosity of milk plasma, Pa·s.

There are evidences [1], that the milk plasma viscosity increases during storage due to increasing acidity, but these changes are insignificant and the decreasing of quality of the milk separation with the acidity 22 - 21 °T is caused primarily by the presence of increased amounts of the coagulated proteins.

More significantly the viscosity of milk plasma is affected by the heat treatment at temperatures above 100 °C [2], and the duration of exposure to heat, which is beginning to manifest itself well at temperatures above 80 °C [3]. These phenomenon are thought to be connected with the beginning of protein denaturation [4], which comes along with the formation of melanoidins (the Maillard reaction).

2.2 Milk fat

It is considered that fat globules have spherical shape although large particles can be oval. As it is little amount of oval particles, in calculations the fat globule with sufficient reliability can be considered spherical, consisting of the milk fat covered with a protein membrane. Existence of a protein membrane on a surface of fat globules not only stabilizes a fat emulsion, but also influences the average density of dispersible particles, non-settling diameter and, of course, separation velocity.

Density of a fat globule taking into account thickness and density of a protein membrane can be determined on a formula [4]

$$\rho_{fgl} = \rho_{sh} - \frac{d_f^3}{d^3}(\rho_{sh} - \rho_f) = \rho_{sh} - \frac{(d-2\delta)^3(\rho_{sh}-\rho_f)}{d^3} =$$
$$= \rho_{sh} - \left[1 - 6\frac{\delta}{d} + 12\left(\frac{\delta}{d}\right)^2 - 8\left(\frac{\delta}{d}\right)^3\right](\rho_{sh} - \rho_f) \qquad (3)$$

Where:
ρ_{fgl} - Density of fat globule (kg/m³); ρ_{sh} - Density of membrane substance (kg/m³); ρ_f - Density of milk fat (kg/m³); d - Diameter of fat globule (m); d_f - Diameter of a fat forming fat globule (m); δ - Thickness of MFGM, (m).

Value of $\frac{\delta}{d}$ is rather small therefore it is possible to neglect items where this relation is to the power of two and three. Then we receive

$$\rho_{fgl} = \rho_{sh} - \left(1 - 6\frac{\delta}{d}\right)(\rho_{sh} - \rho_f) \qquad (4)$$

and, after transformations:

$$\rho_{fgl} = \rho_f + 6\frac{\delta}{d}(\rho_{sh} - \rho_f) \qquad (5)$$

or

$$\rho_{fgl} = 6\frac{\delta}{d}\rho_{sh} + \rho_f\left(1 - 6\frac{\delta}{d}\right) \qquad (6)$$

If to assume that thickness of MFGM does not depend on the particle sizes, i.e. process of adsorption of protein matters of milk plasma goes evenly on all the interface fat-plasma and at the same time the density of membrane substance is a constant value, then the density of a fat globule is a function of the temperature and the diameter of particles, and also is depended on the thickness of a protein membrane.

The milk fat, which is contained in fat globules represents the complex consisting of the homologies (glycosides), the composite lipids (phospholipids), the lipid derivatives, the free fatty acids and substances soluble in a glyceride melt corresponding to fat. Therefore, melting point of milk fat is caused by its tri-glyceride structure and depends on the nature of distribution of fatty acids. Temperature at which milk fat turns into liquid state fluctuates in the range of 27 - 34 °C.

Density of a milk fat can be determined by a formula [4]:

$$\rho_f = 971.95 - 0.024\ t \text{ - at a temperature 5 - 30 °C}$$
$$\rho_f = 931.78 - 0.6724\ t \text{ - at a temperature 30 - 80 °C} \qquad (7)$$

The second of formulas is of interest in calculation of a process of milk separation, which is carried out by warming up of a product beforehand up to temperature 35 - 45 °C or even up to higher temperature.

Density of the adsorption layer can be accepted equal 1320 kg/m³ [5], then in a final look we receive:

$$\rho_{fgl} = 931.78 - 0.6724\,t + 6\frac{\delta}{d}(388.22 + 0.6724\,t) \qquad (8)$$

In the early researches [6], MFGM thickness was taken equal to 0.003 - 0.012 μm with the maximum possible value thought to be 0.036 μm. Later researches [7, 8, 9, 10, and 11] by using methods of electron micrograph, X-ray and ellipsometry obtained different values, varying from 3 - 4 nm up to 9 - 10 nm. In the work [12], it was suggested that in the raw milk thickness of MFGM is averaging at 0.007 μm, which is in accordance with milk separation practice.

When density of milk-fat globule is equal to density of milk plasma ($\rho_{fgl} = \rho_{pl}$) it is impossible to separate milk fat from the plasma. Graphical solution of this equation is showed on Figure 1 [4].

Thus, non-settling diameter of a fat globule is in range about 0.7 - 1.25 μm depending on the thickness of a membrane layer at change of the last from 0.003 to 0.007 μm.

The quantity of fat globules in milk varies in the considerable limits: on average in 1 cm^3 there are from 2 to 6 billion pieces. The sizes of fat globules vary over a wide range: from 0.5 to 10 μm. Generally, particles of size 2 - 5 μm prevail. Fat globules more than 10 μm and less than 0.5 μm in size meet seldom.

Distribution of fat globules by the sizes, as well as fat content of milk, depends on a breed of cow, an age of an animal, the period of year and some other factors. For example, with age in cow's milk the quantity of large fat globules increases, and by the end of a lactation the amount of shallow fat globules increases [4].

Typical distribution of milk fat globules by their sizes is presented on Figure 2 [13].

Distribution of fat globules in milk can be described by the formula of normal and logarithmic distribution. Then quantitative distribution of fat globules in milk can be described in the form of normal and logarithmic law on a formula [4]:

$$D_q = 133.0 \int_{-\infty}^{\lg D} \exp\left[-\frac{\lg D - 0.28}{0.18}\right]^2 d(\lg D) \quad (9)$$

and volume distribution

$$D_{vol} = 293.3 \int_{-\infty}^{\lg D} \exp\left[-\frac{\lg D - 0.58}{0.037}\right]^2 d(\lg D) \quad (10)$$

The results acquired by these formulas are in accordance with data shown on Figure 2.

The disperse structure of fat in milk can change at mechanical impact on milk, which in the course of its receiving and processing at the enterprises of the lactic industry is inevitable. This is reflected in the fragmentation of the large fat globules, or its aggregation, congestion, its merge, and depends on a machine design, operating conditions on them, temperature, and acidity of milk.

At pumping of milk, in particular, takes place a dispersion of large fat globules (4 - 6 μm and more) with the simultaneous decrease of amount of shallow globules (less than 2 μm) and with the increase of amount of average globules [4]. Also takes place partial destabilization of fat, which increases with an increase of: 1) pump head in a pressure line, 2) fat content 3) acidity of milk; and also at an entrainment of air (air trapping) into milk. Centrifugal pumps destroy a fat phase more, than rotational (volumetric) ones.

Mixing of a raw milk in the course of storage does not significantly influence a dispersion and stability of a fat phase. However, multiple mixing and transfusion of milk in the course of the long-term storage (before it is delivered to milk enterprises) reduce stability of a fat emulsion. So, in raw milk the content of the destabilized milk fat makes 0.3 - 0.7%, and in processed - 1.1 - 2.5%.

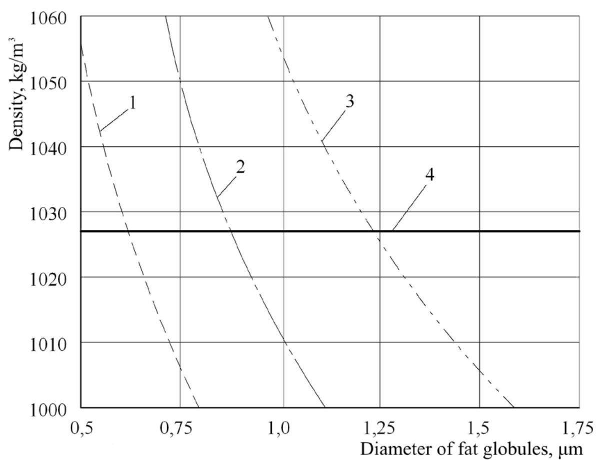

Figure 1. Dependence of fat globule density on its diameter and thickness of membrane. 1 - δ = 0.003 μm; 2 - δ = 0.005 μm; 3 - δ = 0.007 μm; 4 - density of plasma

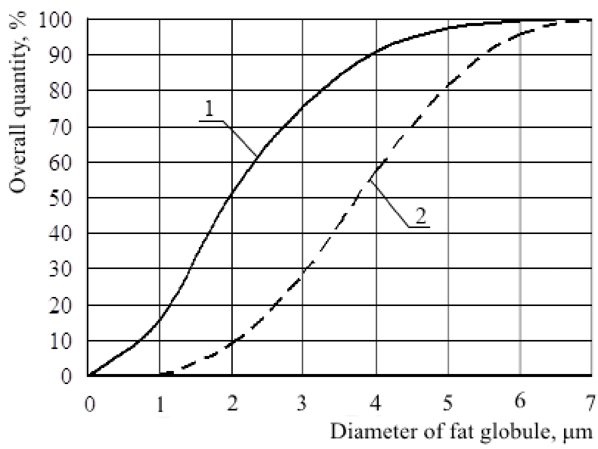

Figure 2. Distribution of fat globules in milk: 1 - quantitative distribution, 2 - volume distribution

The knowledge of exact data of density and viscosity of milk components and their disperse structure and distribution allows to accurately calculate the value of separability of disperse system 'milk fat globules - milk plasma.

2.3 Microorganisms and mechanical impurities

Solid particles form the dispersed phase that allows to consider milk as suspension. The structure of this dispersed phase contains by three principal components: mechanical impurities, the smallest particles of coagulated proteins and microorganisms. Moreover, the third take the important place since, unlike the first and second, their amount constantly increases. Besides, at centrifugal purification of milk only large microorganisms are separated, while the greatest possible selection including small microorganisms can only be provided by the process of bactofugation.

At separation of the milk, the considerable proportion of the microorganisms that are contained in it is removed. The quantity and structure of the microorganisms that are contained in milk depend on many factors bound to the: state of health of cows, service personnel, cattle conditions of keeping, sanitary and hygienic conditions of receiving and primary processing of milk, transportation conditions, milk storage period before separation and its temperature during separation.

Depending on certain conditions, the quantity of microorganisms in milk changes in a wide range (from thousands to tens of millions in 1 cm^3). Density of microorganisms makes from 1,000 to 1,130 kg/m^3 that can be used when calculating process of a bactofugation of milk [1].

The sizes of microorganisms vary in the wide range: from 0.01 to 6 microns. Their distribution on dimensional classes in milk can be absolutely various depending on a condition of microflora.

The heavy dispersible particles separated under the influence of a centrifugal force settle in mud space (sediment space) of a bowl of a separator, forming so-called separator sludge. Outwardly, separator sludge looks like slush of dirty-gray color. In many cases, it is condensed so that it turns into a ring-shaped monolith with elastic rubber-like properties.

Sludge density in the top layer of mud space of a separator makes 1330 - 1360 kg/m^3, on average - 1360 - 1440 kg/m^3, in lower layer - 1440 - 1920 kg/m^3 [1]. Density of separator sludge is changing with a temperature in a small degree therefore practically it can be considered as a constant.

As density of separator sludge is not identical in different layers, for technological and design calculations of milk clarifiers as an initial value the least value of density of separator mucilage equal 1,330 kg/m^3 is accepted [4]. It allows to count process of clarifying at the most severe conditions.

The particles of coagulated protein passing into separator sludge at purification of milk make from 2 to 10 microns, and their quantity and disperse structure is defined, first of all, by acidity of milk. There are no data found on such distribution, but it is reasonable to consider that their centrifugal separation is similar to release of mechanical impurity [4].

Considering the smaller size of many microorganisms than particles of mechanical impurity, at a bactofugation of milk a centrifugal field of bigger magnitude (compared to centrifugal clarification) is created.

The knowledge of exact data of density of mechanical impurities and microorganisms and their disperse structure and distribution allows to accurately calculate the value of separability of disperse system 'milk mechanical impurities - milk plasma.

2.4 Milk separability

The ability of milk as a disperse system to be decompound, including by means of separation, can be described by the characteristic called separability and calculated using following formula [14]:

$$E = \frac{\rho_{part} - \rho_{med}}{\eta_{med}} \cdot \frac{3(\eta_{med} + \eta_{part})}{2\eta_{med} + 3\eta_{part}} \cdot r^2 \qquad (11)$$

Where:
E - milk separability, s; ρ_{part} - density of a dispersed phase (particle), kg/m^3; ρ_{med} - density of a dispersed medium (kg/m^3); η_{part} - viscosity of a dispersed phase (particle), Pa·s; η_{med} - viscosity of a dispersed medium (Pa·s); r - radius of the smallest particle (m).

Separability of disperse system 'milk fat globules - milk plasma' is shown on Figure 3 [4].

Separability of disperse system 'mechanical impurities - milk plasma is shown on Figure 4 [4].

Values of separability of milk dispersed systems calculated in dependence of physical-mechanical properties and temperature of milk allows to calculate the separation process more accurately and therefore could be used in calculations of separators of different construction.

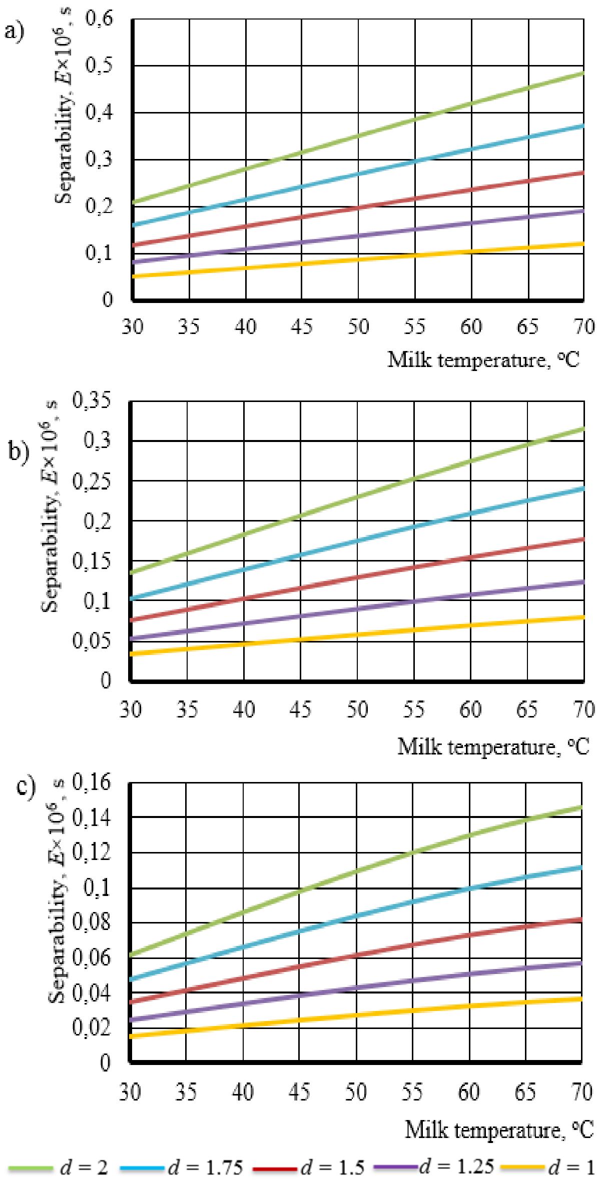

Figure 3. Separability dependence of system 'milk fat globules - milk plasma' on temperature of milk: a) δ = 0.003; b) δ = 0.005; c) δ = 0.005; δ – MFGM thickness (μm), d - diameter of milk-fat globule (μm)

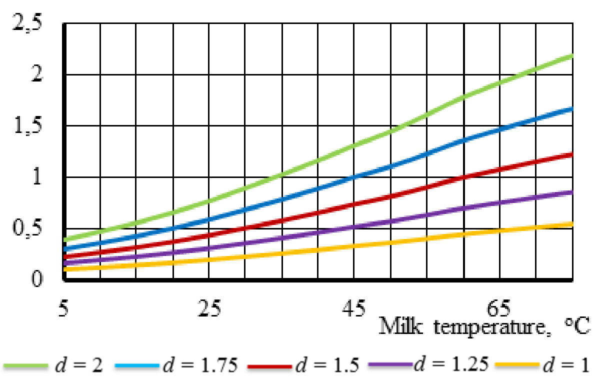

Figure 4. Dependence of system 'mechanical impurities – milk plasma' on temperature of milk; *d* – mean diameter of mechanical impurity particle (μm)

3. Conclusions

- From the separation point of view milk and its components as dispersion systems are reviewed. The characteristics of milk, such as: density and viscosity of milk plasma, density of milk fat globules, thickness of milk fat globule membrane, size distribution of fat globules and mechanical impurities are covered. Based on this data values of separability are presented.

- The value of separability of disperse system milk fat globules - milk plasma within the range of temperature 30 - 70 ^{0}C could be used in calculation of separation process in separators-clarifiers to obtain precise results of centrifugal milk clarification.

- The value of separability of disperse system 'milk mechanical impurities - milk plasma within the range of temperature 5 - 75 ^{0}C could be used in calculation of separation process in separators-purifiers to obtain precise results centrifugal milk purification.

- Properties of separators sludge, which is created in course of whole or skim milk purification and affects the separation process productivity, and the sizes of its particles are still to be discovered.

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