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METHODS OF CONCENTRATION AND THEIR EFFECT ON THE TECHNOLOGICAL PROPERTIES OF POWDERED MILK

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Keywords: milk powder, hyperfiltration, quality, vacuum evaporation, reverse osmosis, dispersibility, cryoconcentration.
Abstract. The article presents the results of a study on the effect of concentration methods used in the dairy industry as a preliminary stage of milk thickening before spray drying on the technological properties of powdered milk. Powdered milk (PM) is a widely used ingredient implemented in the production of various types of food products in dry or reconstituted form; the quality of the finished product depends on its condition and technological properties. One of the significant factors influencing the quality characteristics of the lubricant and the formation of its technological properties are the processes used in its manufacture, including the obligatory production stage such as preliminary concentration (thickening). The study of scientific and technical materials revealed the demand for updating knowledge and structuring information that considers the effect of various concentration methods on the quality of PM. The following methods are considered in this study: vacuum evaporation, hyperfiltration, and cryoconcentration. Their brief description is provided.

СПОСОБЫ КОНЦЕНТРИРОВАНИЯ И ИХ ВЛИЯНИЕ НА ТЕХНОЛОГИЧЕСКИЕ СВОЙСТВА СУХОГО МОЛОКА

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Ключевые слова: сухое молоко, гиперфильтрация, качество, вакуумное испарение, обратный осмос, диспергируемость, криоконцентрация.
Аннотация. В статье приведены результаты исследования о влиянии применяемых в молочной промышленности способов концентрирования в качестве предварительного этапа сгущения молока перед распылительной сушкой на технологические свойства сухого молока. Сухое молоко (СМ) является широко применяемым ингредиентом, используемым в производстве различных видов пищевых продуктов в сухом или восстановленном виде, от кондиции и технологических свойств которого зависит качество готовой продукции. Одним из значимых факторов, оказывающих влияние на качественные характеристики СМ и формирование его технологических свойств, безусловно считаются процессы, используемые при его изготовлении, в т.ч. такой обязательный производственный этап, как предварительное концентрирование (сгущение). Изучение научно-технических материалов выявило востребованность в обновлении знаний и структурировании информации, рассматривающей влияние различных методов концентрирования на качество СМ. Рассмотрены следующие способы: вакуумное испарение, гиперфильтрация, криоконцентрирование. Приведено их краткое описание.

Introduction. The quality and safety of any finished food product firstly depends on the composition and properties of the raw materials; secondly, on their efficient processing using traditional, modernized, modern and innovative technologies, as well as its proper storage conditions.

Powdered milk (PM), having a high nutritional value due to its macro-and micro components, various functional and technological properties, long shelf life, is widely used as a raw ingredient in many food industries. The “lifetime” formation of PM indicators determines its technological and economic feasibility of application.

In the process of industrial production of lubricants, one of the mandatory technological operations preceding the stage of spray drying is concentration (thickening), i.e. removal of part of the moisture from the original milk raw materials to achieve the required mass fraction of solids. Carrying out the drying process without prior concentration is not economically feasible. For example, while thickening the milk using vacuum evaporators, the steam consumption for evaporating 1 kg of moisture is 0.5 kg, and it is 2.5-3.5 kg while spray drying. In addition, the PM produced without pre-concentration has worse quality characteristics than the product produced with the use of thickening [1].

Concentration is carried out using various equipment based on physical methods, which allow us to preserve all the nutritional properties of the constituent parts of milk and their ratio as much as possible and to produce practically only moisture removal. However, many domestic and foreign studies have established that the main structural and functional transformations in raw milk occur before drying; in other words, it occurs at the stages of heat treatment and concentration.

With regard to PM, there are three concentration methods that are mainly used (vacuum evaporation, hyperfiltration, and cryoconcentration), each of which has its own technical and technological advantages and disadvantages.

Vacuum evaporation (VE – evaporation under vacuum) in our country is the most common method of thickening milk since in the last century it was the massive equipment of milk canning plants with progressive vacuum evaporators of various designs and performance, including supplies with the drying equipment. Due to an artificially created vacuum, with this method, intensive boiling of milk occurs at lower positive temperatures (30-60ºC) than the boiling point of milk at atmospheric pressure (100.2-100.5ºC).

The free moisture from the boiling milk turns into steam; it is then continuously removed from the boiling zone. In this case, the concentration of milk solids reaches 40-52%. With water vapor, not only undesirable odors of feed or other origin are removed, but also some of the native aromatic substances and low molecular weight fatty acids are also removed (up to 15% of the original amount) [2, 3].

Hyperfiltration (HF – based on the phenomenon of reverse osmosis) consists of filtering milk at rather low positive temperatures of 4-50 °C and a pressure of 3-6 MPa through membranes with a pore size of 10-4-10-3 μm. As a result, water without phase transformations is extracted from milk systems. In the absence of undesirable thermal effects, the integrity and ratios of the constituent parts are maintained, and there is also no loss of volatile flavor compounds. HF allows concentration of solids for whole milk up to 18%, and for the skimmed milk up to 30-35%. This method of preconcentration is promising in the production of

lubricants in addressing the problem of the need for periodic cleaning and replacement of filter elements, as well as reducing their cost [4].

Cryoconcentration (CC – freezing water) allows us to maximize the original properties of raw milk through the use of a process that takes place at relatively low negative temperatures (from 0 to minus 20ºC). Part of the free moisture in the milk is frozen out, and the resulting ice crystals are removed. The improvement of the CC technology and the hardware design of cryoconcentrators makes it possible at present to create high-performance equipment alternative to vacuum evaporators and membrane plants with the lowest possible losses of solids (less than 1%, consisting mainly of lactose and minerals), which, due to the exclusion of thermal effects, does not lead to significant biochemical changes and allows us to save heat-labile components of milk as proteins and aromatic compounds. With CC, the mass fraction of solids increases to 25-40%.

The study of specialized literature showed that there is a demand for updating knowledge and structuring modern scientific information that evaluates the impact of various concentration methods on the quality of PM. [5]

The aim of research. Analysis and systematization of information on the effect of concentration methods used in the dairy industry as a preliminary stage of milk condensing before spray drying on the technological properties of PM.

Results and discussion. The composition of lubricants, the size and shape of dry particles, solubility, dispersibility, wettability, and other factors have a significant impact on such basic technological and functional properties as reducibility, thermal stability, and cheese suitability.

The study of the composition of skimmed milk powder (SMP), obtained using VE, HF and CC, indicated that all methods of concentration provided a product of a standardized physical and chemical composition with mass fractions of moisture (2.46%; 1.92%; 3.5 %), fat (1.3%; 1.2%; 1.4%), protein (36.27%; 36.16%, 36.10%), and lactose (54.5%; 54.0% ; 52.0%) respectively. At the same time, the difference between SMP-CC in terms of lactose content from SMP-VE and SMP-HF was noted. The reason behind this process is that some of it was removed with the ice fraction, while the VE and HF processes do not influence the distribution of lactose between the condensed milk and the moisture removed. As for ash, the researchers did not observe significant deviations in its content in all samples of SMP (6.7±0.3%) [6].

Similar trends were obtained for whole milk powder (WPM). It was also noted that, regardless of the degree of concentration, the fat remains in the emulsion state, and if no destabilization of the fat emulsion is detected before thickening, then no new structure of the fat phase is formed subsequently. Fat globules come together, but they do not stick together.

An analysis of the PM microstructure using scanning electron microscopy revealed a discrete structure of powders using VE and HF, while CC promoted the formation of predominantly agglomerated particles. The study of the granulometric composition of SMP showed that SMP-VE is characterized by a smaller average particle size (70 μm) than SMP-HF and SMP-CC (105 μm).

It should be noted that the above results are consistent with the literature, including both experimental and industrial data: PM particles obtained by spray drying usually have a diameter of 10 to 250 microns, which depends not only on the composition and properties of the original milk, but also on the heat treatment procedures and pre-concentration. During the thickening process, the proteins increase in size and contribute to an increase in the viscosity of the concentrates before drying. The PM particles also become coarser as the degree of thickening increases, and when the concentration is insufficient, the particle sizes become minimal with the inclusion of a large amount of air, which initiates the development of negative oxidative processes in the PM during storage. In addition, the authors made an assumption that it is the temperature of the air entering the drying tower that has a more intense effect on milk concentrated with the help of HF and CC, since these two methods include lower temperatures for processing the initial milk during thickening, which practically do not affect the protein fraction [7].

In the samples restored to a solids content of 25%, there was revealed a monomodal distribution of casein micelles with a size of 70-400 nm, which is commensurate with the size of micelles in raw milk. The largest average size was observed in reconstituted milk using CC (190 nm); while for VE and HF, this indicator had a value of 164 nm. This is due to the fact that CC reduces the size of casein micelles, which, under the influence of heat during the drying process, easily agglomerate, forming larger particles consisting of denatured whey proteins and casein micelles. The authors also determined that the irreversible denaturation of the main whey proteins (β-lactoglobulin and α-lactalbumin) occurs mainly during the heat treatment preceding the thickening stage, and, thus, the effect of concentration on their denaturation is considered minimal.

The paper presents similar studies of the priority effect on the thermal stability and cheese suitability of PM of heat treatment before concentration and drying. The toughening of temperature effects on milk systems before thickening leads to a progressive increase in the denaturation of whey proteins and the enlargement of casein micelles, which contributes to the production of a heat-resistant PM with a weak gel-forming ability.

An important characteristic of protein thermal stability and gel formation strength is the zeta potential, the value of which is influenced by the calcium content; the removal of some of its amount from milk systems improves their thermal stability. The data obtained by the authors did not show any significant differences between the restored samples using VE, HF and CC (-28.2; -26.6; -27.1 mV, respectively). However, the researchers found that the use of CC before drying contributed to the partial loss of calcium with the ice fraction and the formation of a weaker gel compared to dense gels obtained using VE and HF, during which moisture is removed in the form of steam or pure water. The authors present data on the thermal stability of PM obtained using HF, which contributed to the maximum retention of ionic calcium 1.25 ± 0.02 mM in the retentate and a decrease in active acidity (pH 6.30 ± 0.04), which negatively affected the thermal stability of the system.

Solubility is the basic criterion for assessing the quality of lubricants; it is characterized by a complex physical and chemical process that depends on many factors (the structure and composition of the main components, process conditions, etc.). The solubility of PM is closely related to cumulative changes in the protein, crystallization of lactose and the ratio of its α- and β-forms (β-lactose is more soluble), recovery conditions, etc. Powdered dairy products are considered almost completely reduced if their solubility index is above 99%, in other words, the content of insoluble sediment should not exceed 1%. The maximum solubility values for PM-VE, PM-HF, and PM-CC were 91, 94, and 97%, respectively. The best solubility of PM-CC is due to the agglomeration of PM particles and a lower content of mineral substances.

With the help of dispersibility, the instantaneous recovery of PM during rehydration is assessed. WMP is considered to be well dispersible if its index is above 85%, and if SMP is above 90% (with the improvement of the drying process, a value above 95% will be considered ideal). Dispersibility depends on the granulometric profile of the powder, drying parameters, reduction conditions, etc. Determination of the dispersibility of SMP showed low values: 65% (VE), 69% (HF), 74% (CC), which means that thickening methods do not affect this parameter. However, all types of milk with a particle size of 105 nm had a good dispersibility index (92-93%), which decreased with increasing size.

Wettability is the ability of the PM to sink into water, i.e. to absorb it on the surface. In this case, we can obtain swelling and dissolution of proteins. The wettability is mainly influenced by the lactose content, size, porosity and capillarity of dry particles, as well as reduction conditions, etc. PM is considered to be perfectly wettable if this indicator does not exceed 20-30 s. The indicated values correspond to instant PM. The paper presents the results of wettability of SMP: 2060±35 s (VE), 2030±33 s (CC), 2010±28 s (HF). The use of HF contributed to a slightly better wettability; however, taking into account the error values, the differences in indicators are leveled and all types of milk can be classified as poorly wettable and attributed to conventional PM, which is mass-produced by dairy canning enterprises [7, 8].

Conclusion. In the process of pre-concentration of raw milk during the production of PM, complex physical, physico-chemical and biochemical processes occur that affect the functional and technological properties of the finished product. Currently, VE is effectively used for the manufacture of all types of milk powder (skimmed, partially skimmed, and whole). HF and CC are used mainly in the development of SMP. The studied types of preconcentration (VE, HF, CC) ensured the production of PM standardized in terms of physicochemical composition. CC made it possible to develop a product consisting of agglomerated particles, which contributed to better solubility compared to the use of VE and HF. None of the types of thickening had any significant effect on the dispersibility and wettability of PM. The thermal stability of PM was also almost the same with some minor differences while using CC. The heat treatment before thickening and drying has a dominant influence on the thermal stability and cheese suitability of PM.

Further study of the characteristics of milk concentrates in the production of PM obtained by various methods, especially in relation to the WMP (due to insufficient data at the moment), will expand the understanding of the effect of concentration on the quality of dry dairy products.

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