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INVESTIGATION OF VACUUM-ATMOSPHERIC DRYING OF CAMEL AND MARE'S MILK

Abstract. The relevant problem of dehydration of dairy products is a subject of research in this issue. Camel and mare's milk are of interest in this regard. Actually, for these products energy-intensive methods of vacuum and vacuum-sublimation drying are usually used, that is explained by high preservation of biochemical composition of dried materials. It causes the problem of further study and improvement of various aspects of drying processes. A method of vacuum-atmospheric drying of camel and mare's milk is proposed, based on their dehydration in a drying plant where these processes are carried out in a parallel way. Combining processes should be based on the selection of modes of the above-mentioned drying methods. Experimental studies of vacuum-atmospheric drying of camel and mare's milk depending on pressure and temperature of heating the medium in the vacuum chamber, as well as the speed and temperature of drying agent in the device for atmospheric drying have been conducted. Empirical equations allowing describing quite adequately processes of heat and mass transfer at vacuum-atmospheric drying of dairy products are received.

Keywords: vacuum, drying, camel, mare, milk, method, atmospheric.

Introduction

The issue in developing of new and innovative drying techniques is still actual one [1, 2]. Main reasons to accelerate attempts for development of advanced drying techniques are: making the process cost effective, reducing the energy consumption, intensifying the drying rates, improving the quality of dried food products, increasing safety in operation and making the drying process easy to control [3, 4]. Particularly relevant in this aspect is solution of problem of dehydration of dairy products. Camel and mare's milk are of interest in this regard. In practice, for these products energy-intensive methods of vacuum and vacuum-sublimation drying are usually used, that is explained by high preservation of biochemical composition of final product. It causes the problem of further study and improvement of various aspects of drying processes. In the aspect of solving this problem, a method of vacuum-atmospheric drying of camel and mare's milk is proposed, based on their dehydration in a drying plant in which these processes are carried out in a parallel way.

The essence of the developed process of vacuum-atmospheric drying of liquid materials is consists of combination into a single process of separate experimentally obtained processes of vacuum and atmospheric drying. The developed method includes vacuum drying of milk to a certain intermediate humidity and its atmospheric drying to the final humidity. In this case, the drying process is accelerated due to the parallel implementation of vacuum and atmospheric drying processes. Since atmospheric drying is carried out by using the condensation heat of the working substance of a refrigeration machine included in the drying plant according to heat pump scheme. A moderate temperature difference is created, equivalent to temperature head during vacuum drying. Also, by using condensation heat of refrigerant to heat the dried material, a gentle mode of milk drying in the vacuum chamber is achieved. Drying of the

material is carried out by air heated by waste heat of condensation of refrigerant, which saves the energy of heating the drying agent.

The developed experimental drying plant implementing the developed method of vacuum-atmospheric drying of dairy materials includes units of vacuum drying, heat pump and atmospheric drying [5]. In the installation, the vacuum drying unit provides the drying process of materials in a rarefied medium from the initial moisture content to the intermediate one. The heat pump unit provides high-potential heat to the atmospheric drying unit and low-potential heat to the moisture defroster of the drying unit. The unit of atmospheric drying of materials provides the process of atmospheric drying of thermolabile materials from the intermediate humidity of the material to the final one, regulated by technical requirements for the finished product.

Experimental methods

The study of vacuum and atmospheric drying processes in order to further combination them into a single process of vacuum-atmospheric drying was carried out under the following conditions:

- vacuum drying: pressure of medium – (6÷10) kPa; temperature of heating of medium - (35÷45) ^{0}C; height of dried layer is 0.01 m.

- atmospheric drying: drying agent temperature - (36÷40) ^{0}C; drying agent velocity - (0,35÷0,45) m/s.

Selection of temperature and pressure intervals during vacuum drying was substantiated by necessity for maximum preservation of biochemical composition of investigated drying materials at a sufficiently high intensity of drying process. The choice of temperature intervals and drying agent velocities during atmospheric drying of materials was determined by the same reasons.

The necessary of combination and selection of optimal modes of vacuum and atmospheric drying was carried out in such a way as to ensure a uniform character of the drying process of the material, which would take place only in vacuum or only in atmospheric drying. In practice, the combination of drying modes was carried out by studying the nature or kinetics of vacuum and atmospheric drying processes, the selection of humidity and temperature of material in the process of dehydration, as well as selection of material moisture to which it is advisable to carry out the vacuum drying process. Accordingly, when the dried material reaches that humidity level, the process of atmospheric drying begins.

Processing of results of experimental studies of vacuum and atmospheric drying showed that for the developed vacuum-atmospheric process it is recommended to combine the following drying modes:

- vacuum drying at pressure of medium 6 kPa and heating temperature of medium 40 ^{0}C with atmospheric drying at air temperature 40 ^{0}C;

- vacuum drying at pressure medium 10 kPa and a heating temperature of medium 40 ^{0}C with atmospheric drying at air temperature 36 ^{0}C;

- vacuum drying at pressure medium 8 kPa and a heating temperature of medium 45 ^{0}C with atmospheric drying at air temperature 38^{0}C.

Under these conditions, there is not only a high intensity of the drying process, but also the absence of kick of milk from a container. Also, the optimal velocity of the drying agent in the atmospheric drying device was determined experimentally, which was equal to 0.35 m/s at heating temperatures (36÷40) ^{0}C.

Experimental studies of vacuum-atmospheric drying of camel and mare's milk depending on pressure and temperature of heating the medium in the vacuum chamber, as well as the velocity and temperature of drying agent in the device of atmospheric drying have been conducted. As it known, drying is a complex operation involving simultaneous heat and mass transfer processes [3].The results of experimental studies, processed in the form of heat and mass transfer coefficients for camel and mare´s milk are shown in figures 1-4.

Results and discussions

The figure 1 shows that when the heating temperature of medium increases from 35 to 45 ^{0}C, the values of heat transfer coefficients increase by 11.4÷14.2 %. At the heating temperature of vacuumed medium 45 ^{0}C with a deepening of rarefaction of medium from 10 to 6 kPa, the values of the heat transfer coefficients increase from 3.55 to 4.89 W/(m^{2}K), i.e. by 27.4 %. With deepening of rarefaction of medium, the values of mass transfer coefficients, as well as the heat transfer coefficients, increase (figure 2). The greatest break is observed when the degree of rarefaction of medium decreases from 10 to 6 kPa at

temperature of heating 45 ^{0}C, when values of mass transfer coefficients increase from 0.11 to 0.17 s/m or by 35.3 %. At 40 ^{0}C this figure is increased b 26.4%, at 35 ^{0}C by 32.9%.

A similar change in heat and mass transfer coefficients from the drying modes is observed during vacuum drying of mare's milk.

In view of the above, the optimal mode of vacuum drying of camel and mare's milk should be considered as medium pressure 6 kPa and heating temperature 45 ^{0}C.

For atmospheric drying (figures 3 and 4), it can be concluded that in the temperature range (36÷40) ^{0}C, the nature of change in heat and mass transfer coefficients for camel and mare's milk is almost identical. Thus, the value of heat transfer coefficient increases from 3.10 to 4.75 W/(m^{2}K) and the mass transfer coefficient from 0.10 to 0.15 s/m, which is 34.7 and 33.3% for each case.

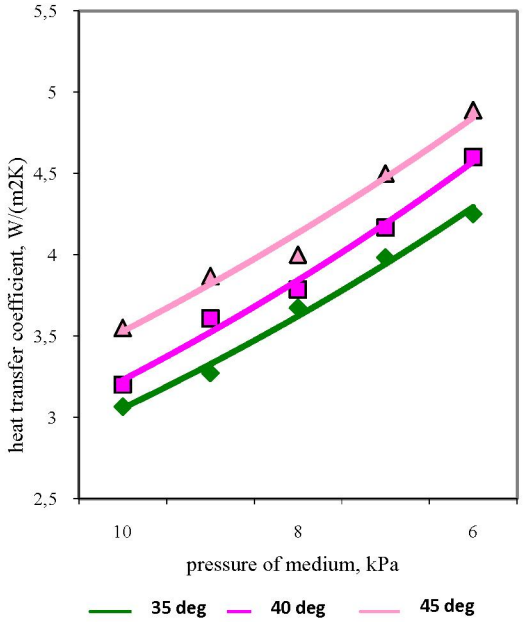

Figure 1 – Dependence of heat transfer coefficient from pressure at various temperatures of heating of medium at vacuum drying of camel milk.

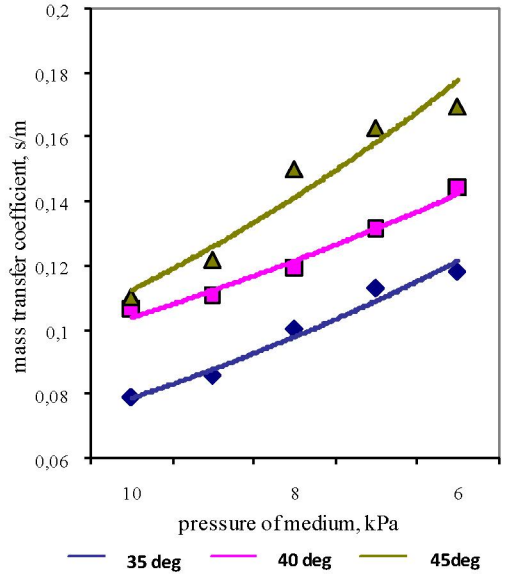

Figure 2 - Dependence of mass transfer coefficient from pressure at various temperatures of heating of medium at vacuum drying of camel milk.

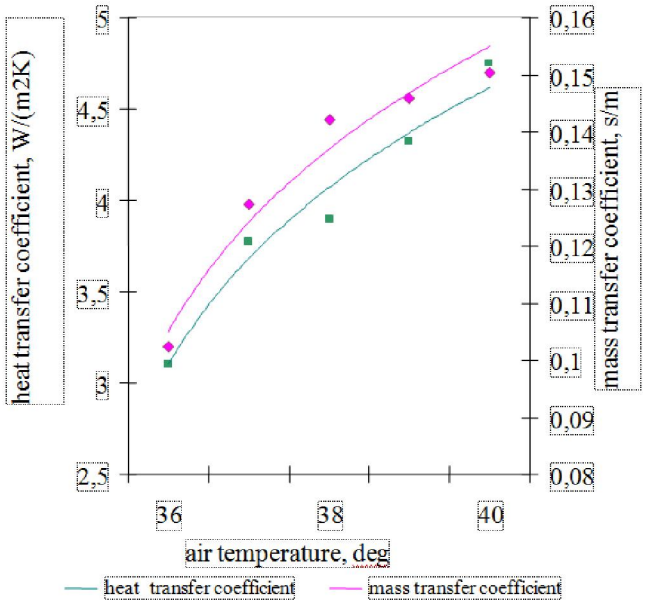

Figure 3 – Dependencies of heat and mass transfer coefficients from temperature of drying agent at air velocity 0.35 m/s at atmospheric drying of camel milk

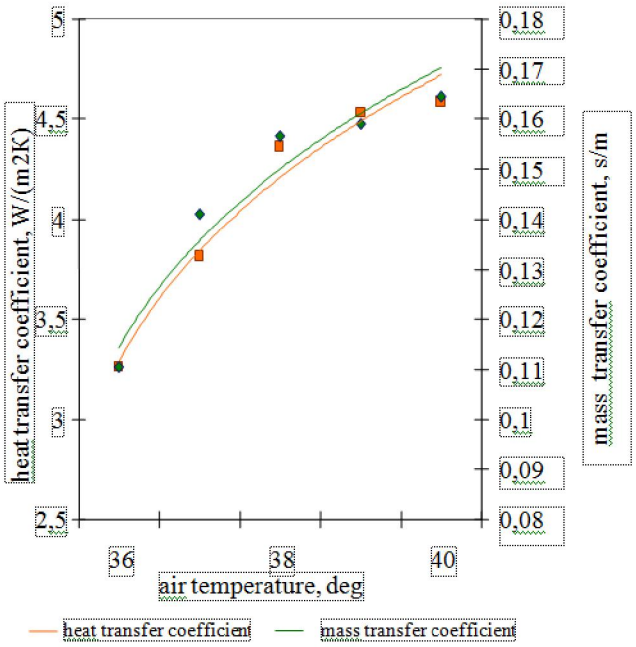

Figure 4 – Dependencies of heat and mass transfer coefficients from temperature of drying agent at air velocity 0.35 m/s at atmospheric drying of mare´s milk

For mare's milk in a given temperature range, the heat transfer coefficient increases from 3.35 to 4.52 W/(m^{2}K) or 25.9%, and the mass transfer coefficient – from 0.11 to 0.16 s/m or 31%. Analyzing figures 3 and 4, it can be concluded that the optimal mode of atmospheric drying should be considered the temperature range of the drying agent (38÷40) ^{0}C.

Based on analysis of experimental data on heat and mass transfer during vacuum - atmospheric drying of camel and mare's milk for the vacuum drying process, the equations of thermal Nu and diffusion Num of the Nusselt criteria are obtained:

$$Nu=5,25\ Pr^{0,33}\ Re^{0,025}\ Gu^{0,47},$$

$$Nu_m=0,056\ Pr_m^{\ 0,33}Re^{0,61}Gu^{\ 0,16}.$$

Also, on the basis of experimental data on heat and mass transfer during vacuum - atmospheric drying of these dairy products, the equations of thermal Nu and diffusion Nu_m of the Nusselt criteria for the atmospheric drying process are obtained:

$$Nu=0,638\ Pr^{0,33}\ Re^{0,16}Gu^{0,26},$$

$$Nu_m=0,71Pr_m^{\ 0,33}Re^{0,18}\ Gu^{0,14}.$$

Conclusion

So, the method of vacuum-atmospheric drying of camel and mare's milk is developed; it includes vacuum drying of material to intermediate humidity and atmospheric drying till final one. It allows achieving good quality of the product and promotes significant decreasing of energy consumption for drying. Also empirical equations are obtained allowing describing the processes of heat and mass transfer at vacuum-atmospheric drying of dairy products.

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ТҮЙЕ ЖӘНЕ БИЕ СҮТТЕРІН ВАКУУМДЫ-АТМОСФЕРАЛЫҚ КЕПТІРУДІ ЗЕРТТЕУ

Аннотация. Берілген мақалада зерттеу нысаны сүтті өнімдерді ылғалсыздандыру өзекті мәселе болып табылады. Осы орайда түйе және бие сүттері қызығушылық тудырады. Тәжірибеде бұл өнімдер үшін әдетте энергия шығыны көп кептірудің вакуумды және вакуум-сублимациялық әдістері пайдаланылады, бұл кептірілуші материалдардың биохимиялық құрамының толық сақталуымен түсіндіріледі. Бұл кептіру процесстерінің түрлі аспекттерін әрі қарай зерделеу және жетілдіру мәселесін қозғайды. Түйе және бие сүттерін кептіру қондырғысында ылғалсыздандыруға негізделген әрі бұл процесстер параллельді жүретін вакуумды-атмосфералық кептіру тәсілі ұсынылды. Процесстерді қиюластыру жоғарыда көрсетілген кептіру түрлерінің режимдерін таңдауға негізделуі тиіс. Температура мен қысым тәуелділігіне байланысты вакуумды камерадағы ортаны қыздыру, сондай-ақ атмосфералық кептіруге арналған құрылғыдағы кептіргіш агенттің жылдамдығы мен температурасы арасындағы тәуелділікке сәйкес түйе және бие сүттерін вакуумды-атмосфералық кептіру бойынша эксперименттік зерттеулер жүргізілді. Сүтті өнімдерді вакуумды-атмосфералық кептіру кезіндегі жылумассаалмасу процесстерін жеткілікті түрде дәл өрнектеуге мүмкіндік беретін эмпирикалық теңдеулер алынды.

Түйін сөздер: вакуум, кептіру, түйенің, биенің, сүт, әдіс, атмосфералық.

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ИССЛЕДОВАНИЕ ВАКУУМНО-АТМОСФЕРНОЙ СУШКИ ВЕРБЛЮЖЬЕГО И КОБЫЛЬЕГО МОЛОКА

Аннотация. Предметом исследования в данной статье является актуальная проблема обезвоживания молочных продуктов. В этом аспекте интерес представляют верблюжье и кобылье молоко. На практике для

этих продуктов обычно используются энергоемкие методы вакуумной и вакуум-сублимационной сушки, что объясняется высокой сохранностью биохимического состава высушиваемых материалов. Это вызывает проблему дальнейшего изучения и совершенствования различных аспектов процессов сушки. Предложен способ вакуумно-атмосферной сушки верблюжьего и кобыльего молока, основанный на их обезвоживании в сушильной установке, где эти процессы осуществляются параллельно. Комбинирование процессов должно основываться на выборе режимов вышеуказанных способов сушки. Проведены экспериментальные исследования вакуумно-атмосферной сушки верблюжьего и кобыльего молока в зависимости от давления и температуры нагрева среды в вакуумной камере, а также скорости и температуры сушильного агента в устройстве для атмосферной сушки. Получены эмпирические уравнения, позволяющие достаточно адекватно описывать процессы тепломассообмена при вакуумно-атмосферной сушке молочных продуктов.

Ключевые слова: вакуум, сушка, верблюжье, кобылье, молоко, метод, атмосферный.

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