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TEMPERATURE CONDITIONS AND DRYING MECHANISM OF SOAP BASE OBTAINED BY RECYCLING WASTE FOOD OIL

Annotation. The possibility of using waste edible oil as a secondary raw material in the production of sanitary and hygienic detergents is described. A model of the drying mechanism of the hygienic soap base and the results of the study of temperature conditions are presented. Model constructions of the drying mechanism of the sodium soap base and the temperature mode of the drying process are considered based on the physicochemical structure and phase composition of the soap composition.

A diagram of a complex cooking and drying unit is presented using the example of producing toilet soap from waste edible oil. A diagram of the mechanism for removing moisture as a result of drying the soap base with a lamellar structure is presented. The results of the study of the temperature mode of the complex cooking and drying unit showed that with a decrease in humidity, the temperature should be minimal and, accordingly, the residual vapor pressure will also be lower. Equations of material and heat balance for the process of producing toilet soap from waste culinary oil are presented. The results of the proposed studies are planned to be used in the production of sanitary and hygienic soap for the service sector, using waste culinary oil as a secondary raw material.

Keywords:ecological load; environment; cooking oil waste; secondary raw materials; utilization; recycling; soap base; drying mechanism; temperature conditions; material balance; heat balance.

Introduction

Interactions and discrepancies between humanity and the natural environment have always existed and continue to have a profound impact on our health and lives. The interrelationship between nature, cycles, alternative energy and energy issues is currently reflected in environmental projects. However, given the imbalances in the world, we need to explore new promising areas, paying attention not only to environmental education, but also to public sanitation and hygiene issues. In order to identify the problems and future opportunities for using waste cooking oil as a secondary raw material for the production of valuable products, it is necessary and relevant to conduct an in-depth study of the processes used in their processing.

Used vegetable oils refer to oils that have been used once or multiple times in cooking. Reusing cooking oil more than twice has carcinogenic effects on human health due to molecular changes in its structure caused by repeated heating at high temperatures. In addition, disposing of waste cooking oil in sewers, rivers, and soil contributes to environmental pollution [1].People around the world consume large amounts of edible oil. Many foods are fried in oil, and cooking oils are primarily derived from plants. On average, a household of four consumes 2–5 kg of vegetable oil per month [2]. Due to the high cost of vegetable oil, catering establishments often reuse it three or more times to cut costs and increase profits. However, reused vegetable oil poses health risks [3].These waste cooking oils are typically disposed of through sinks and drainage systems. Pollution from used cooking oils occurs when they come into contact with local ecosystems. Used cooking oils have harmful effects on the environment, particularly on aquatic flora and fauna [4]. They also contaminate drainage systems, soil, and water sources. Therefore, converting waste streams and waste cooking fat into a valuable new product is a relevant issue [5]. For example, the Belo Horizonte community in Brazil has been repurposing waste cooking oil since November 2020 to produce aromatic soap [6].

According to regulations, although waste cooking oils exist in liquid form, they share a composition similar to animal fats and are not properly disposed of in households, restaurants, or public enterprises. The improper disposal of waste cooking oils leads to clogged sewage systems and the destruction of aquatic flora and

fauna. By utilizing these waste cooking oils for soap production, two key objectives can be achieved: addressing waste management issues and producing sanitary and hygiene products [7].

Authors [8] have proposed the use of waste oil from potato chip production in the manufacturing of scented soap. According to researchers, before repurposing used palm oil for soap production, it must first be purified and decolorized. After this process, up to 30% of non-food-grade oil can be substituted. Accordingly, the main objective of this research is to reduce the volume of exported non-food-grade oil, lower the production cost of scented soap, and minimize environmental pollution.

Population growth, along with changes in consumer lifestyle models, has become a key factor in the increasing volume of waste generation. This, in turn, has negative effects on various components of the natural environment and public health [9]. Over the past decade, waste management has become increasingly complex, and several composting processes for organic waste have been developed. However, despite its low economic value, certain organic waste, such as oils, cannot be composted [10].

According to Directive [11], 62% of waste cooking oil originates from the household sector, while 38% comes from restaurants, hotels, and public catering establishments. There are predictions within the European community that a significant portion of this waste will be collected and processed into biodiesel fuel [12]. However, the actual recycling rate of waste in this sector remains unsatisfactory.

Given the above considerations, the utilization of non-reusable waste cooking oils for the production of secondary sanitary and hygiene products is economically and environmentally significant.

The saponification reaction, also known as the cold process of soap production, involves the alkaline hydrolysis of triacylglycerol's. These esters are the main components of vegetable and animal fats. They react in an aqueous medium with strong mineral bases, such as sodium hydroxide, producing sodium salts of hydrolyzed free fatty acids and glycerol [13].

Historically, soap production has been a method of reusing animal fats. Today, most people use commercially produced soap, but in poorer regions, some families and communities still produce their own soap bars [14; 15]. Furthermore, there are also regions where access to basic handwashing soap is limited, which increases the risk of infection spread in those areas [16; 17]. Moreover, efforts to expand the production of high-quality green soap are ongoing, as it is considered beneficial for human health and skin.

Currently, all plants are recognized as sources of oil raw materials due to their significant oil content. Their composition, when combined with additional additives, allows for the production of soaps with various characteristics [18].

All animals and plants have lipid structures consisting of triacylglycerol mixtures and free fatty acids. However, each species, and even each family, has distinct lipid profiles. This means that when extracting oil from plants, the exact ratio of triacylglycerol's to free fatty acids cannot be precisely determined.

The saponification index of an oil is a key indicator of reaction efficiency. It indicates the amount of potassium hydroxide required for the saponification of a given oil. The saponification index value supports formulation decisions across a wide range of possibilities.

Essential oils are composed of secondary plant metabolites and are responsible for their characteristic aroma. The composition of various aromatic and aliphatic compounds, typically a combination of terpenes and terpenoids, depends on the plant species, variety, geographic origin, soil conditions, and growth stage [19; 20].

While modern cosmetic products use synthetic fragrances, high-end cosmetic manufacturers prefer natural essential oils. However, due to their high volatility, organic fixative molecules are required, such as sucrose, sucrose derivatives, sodium carboxymethyl chitosan, and others [21]. Based on this principle, the use of additional additives has led to an increase in the application of essential oils. However, they do not significantly affect the cleansing function of soap.

The aim of this proposed study is to determine the feasibility of obtaining soap from waste cooking oil through alkaline processing. Additionally, an environmentally optimal method for producing soap from waste cooking oil has been implemented.

Research Methods and Materials

As the research object, waste cooking oil used by urban residents and public catering establishments was selected. The color of the waste oil ranged from yellowish to dark brown-black. It had a strong burnt taste and odor. Its consistency was viscous.Density: 1075 kg/m³. Refractive index at 20°C: 1.893. Viscosity at 20°C: 0.1891 Pa·s. Acid value: 0.74 mg KOH/g. Peroxide value: 5.72 mmol 0/kg.

To ensure the fat content and hardness of sanitary soap, beef tallow was used as the animal fat. Color: yellowish. It had a characteristic odor of natural tallow. Density: 938 kg/m³. Solidification temperature: 30–40°C. Melting temperature: 40–51°C. Viscosity at 20°C: 0.0150 Pa·s. Iodine value: 32–47%.

Sodium hydroxide (NaOH) was used to prepare an aqueous-alkaline solution. In flake form. Density: 2130 kg/m³. Solubility in water at 20°C: 52.2%. Dissolution in water is accompanied by the release of a significant amount of heat. The aqueous-alkaline reaction occurs at 65°C, resulting in a density reduction to 1829 kg/m³.

Sodium liquid glass was used as a practically moisture-resistant binder. Viscous light yellow liquid. Density: 1460 kg/m³. Setting time: 45 min. Silicate modulus: 2.7.

Chemical Processing and Purification of Burnt and Used Cooking Oil.Burnt and used cooking oil was mechanically filtered through a sieve and heated to 80°C. It was then washed with a hot 10% NaCl saline solution. The ratio of used oil to saline solution was set at 10:1. The hot mixture was stirred at 60 rpm in a mixer for 30 minutes, then left to settle for 1 hour to separate into oil and water phases. To determine the required amount of saline solution containing 5% and 10% NaCl, the required amount of saline solution was determined using 50 g of waste cooking oil.After 1 hour, the lower phase (saline solution and impurities) was separated by siphoning. The water layer was discarded, and the purified oil was collected in a separate beaker. To remove moisture, anhydrous sodium sulfate was added to the used cooking oil and filtered through filter paper. To adjust the color of the purified oil, it was treatedwith 5 ml of hydrogen peroxide. The color and impurities of the used cooking oil before and after purification were determined using the method described in [22]. Additionally, the odor was evaluated according to the method described in [23, p. 70].

Decolorization of Purified Waste Cooking Oil.During the processing of purified waste cooking oil, filtration, washing, decolorization, and deodorization were performed. The purified waste cooking oil was heated to 70°C and decolorized using a 2% hydrogen peroxide solution to improve its color.The sample was stirred at 80 rpm in a mixer for 30 minutes while maintaining a temperature of 70°C. The thoroughly mixed solution was filtered through filter paper, and its color was measured.The oil testing was conducted by adding an H_2O_2 solution to one sample while leaving the second sample untreated. The color of both samples was evaluated through visual inspection.

Saponification Process.50 kg of measured animal fat was heated together with 135 L of used cooking oil to a temperature of 70°C.Additionally, 25 kg of sodium hydroxide was added to 32 kg of water to prepare an aqueous-alkaline solution. The preparation of the aqueous-alkaline solution releases a significant amount of heat and must be stirred for a certain period to allow cooling.

The temperature difference between the heated oil mixture and the aqueous-alkaline solution must not exceed ±10°C. The heated oil is mixed with the velocity of 14 rpm after reaching of the required temperature range of soap base. Then the aqueous-alkaline mixture is added into oil mass by cascade method.

The purpose of stirring the oil mixture during the addition of the aqueous-alkaline solution is to prevent excessive foaming and overflow. Next, the mixture of fatty acids converted into alkaline salts is stirred until a uniform viscous consistency is achieved. Once the mixture has reached a homogeneous state, stirring is stopped until the saponification reaction is complete.

The alkali neutralization reaction of fatty acid salts depends on ambient temperature and alkali concentration and takes between 45 and 60 minutes.

The cleansing properties of soap are ensured solely by fatty acid salts. All other substances are entirely unnecessary. To remove them from the soap paste, it is treated with a 7–8% NaClsolution.At this stage, a dense, pure, and concentrated product is obtained. This completes the soap boiling process, and the processing stage of the final mass begins.

To the homogeneous soap paste, 10 kg of liquid glass is added as a binder, and the mixing process is carried out at a speed of 14 rpm. The mixing process is followed by the cooling process. During cooling, an additional ventilator is used to blow air onto the surface of the homogeneous soap paste. Ventilation accelerates the drying process, allowing for the formation of soap granules. The size of the granules depends on the ventilation and cooling conditions and ranges from 0.5 mm to 20 cm. During the cooling and drying process, the temperature of the soap granules decreases to room temperature. The cooled soap granules are passed through a noodle extruder for preliminary compression. The compressed soap noodles are further compacted using a molding machine to form soap bars. Soap bars measuring 55–60 cm in length are packaged according to the specified weight.

Results and Discussion

The concentration of soap base produced using the boiler method ranges between 70% and 85%, with a water content of up to 15–30%. The standard requirements determines the quality parameter of toilet soap to be 74-78% , household soap – 64-70%. To meet standard requirements for the quality index of commercial soaps and to reduce their water content accordingly, the soap base must be dried.

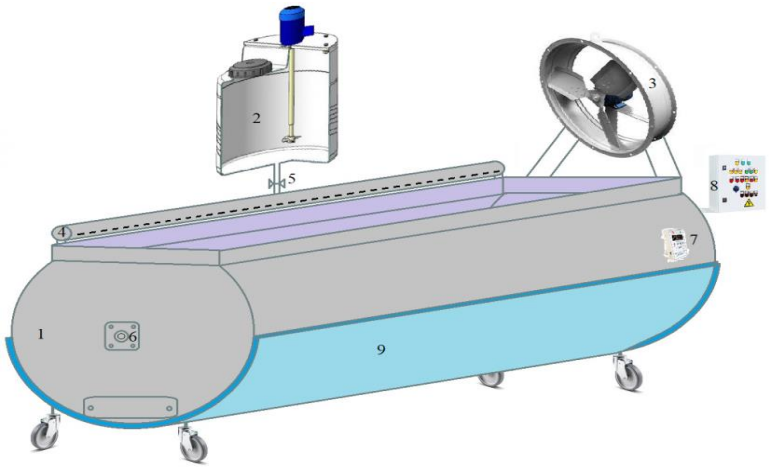
For drying the soap base, industries used vacuum spray dryers introduced by Mazzoni in the 1940s [24; 25]. Despite numerous research efforts aimed at drying the soap base, the calculation of the technological

parameters of vacuum spray dryers is still based on empirical formulas for evaluating the pressure and geometric dimensions of the drying chamber [26, p. 153; 27, p. 18].

This study examines the model construction of the soap base drying mechanism based on the physicochemical structure and phase composition of the soap formulation. The temperature regime of the drying process was analyzed. For drying the soap base, a drum mixer equipped with a ventilator was proposed as part of the integrated boiling and drying unit design.

Diagram of the Integrated Boiling and Drying Unit.The integrated boiling and drying unit is examined using toilet soap as an example (Figure 1). The soap base with a concentration of 74–78% is dried within a temperature range of 80–85°C by applying heat from below and cooling from above.

The lower part of the unit contains an external hollow casing, which acts as a heat exchanger and is filled with water. At the temperature of 80-85°C the soap mass is warmed up to the middle in the low part of the device, and in upper part of the device at heating of soap mass the water vapour is released.



1 – Casing of the integrated boiling and drying unit;2 – Tank equipped with a mixer for preparing the aqueous-alkaline solution;3 – Ventilator for supplying cool air during the soap base drying process;4 – Multi-nozzle pipe for cascading the aqueous-alkaline solution;5 – Valve;6 – Paddle shaft located along the axis of the casing;7 – Temperature sensor;8 – Control unit;9 – Water-filled hollow casing; 10 – Gearbox; 11 – Engine.
Figure 1 – Diagram of the Integrated Boiling and Drying Unit.

The heat released during the cooling of the soap base is utilized for the spontaneous evaporation of water in the soap base. Due to the heat of spontaneous evaporation, the soap base dries, cools, and settles in the lower part of the unit in a dough-like form. The dough-like soap base is mixed by stirring paddles located along the central axis of the unit. This process ensures uniform distribution throughout the entire volume of the soap base of heat from below and cool air from above.

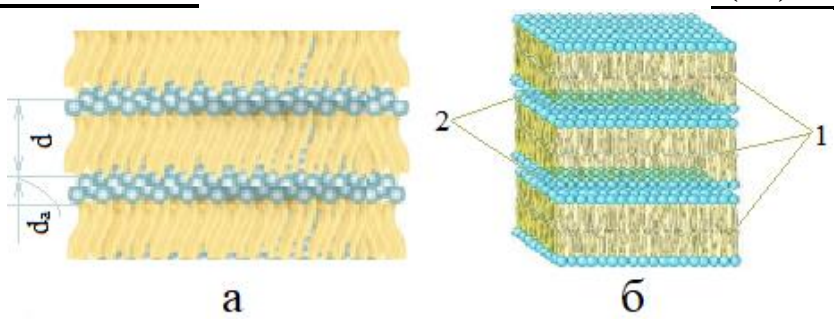
The cool air supplied from above by the ventilator promotes the formation of granules in the soap base. Depending on the ventilation conditions, the granules in the soap base form within a size range of 0.5–150 mm.

The drying system for household soap is not fundamentally different from the drying process of toilet soap. Therefore, additional feeders for silicate liquid glass and fragrance additives are incorporated into the system.

Model of the Drying Mechanism of Hygienic Soap Base.A core soap or soap base with a concentration of 74–78% within a temperature range of 80–85°C consists of a soap-alkali emulsion in a lamellar-structured liquid crystalline phase.This phase contains an alkali layer composed of 2–4% alkali, 0.5% salt, and 0.7% glycerin dissolved in water, as well as alternating layers formed by bilayer amphiphilic molecules (Figure 2).

Waterremovingfromsoapmassbycontact and convective methods of drying occurs very slowly because of the platelet structure of soap, that is very aggregative stable.To solve this problem it become necessary to disturb the soap structurethat is to act thermally on the platelet structure by increasing the temperature of soap base till the point of soap-alkali phase inversion. After this action the soap structure become unstable and disrupted. In general, the temperature of the phase inversion point of the soap base depends on its initial formulation and concentration. For the liquid crystalline phase of toilet soap with a concentration of 74–78%, this temperature is in the range of 100–105°C. The water being in platelet structure of soap base at this temperature boils and evaporates creating the pressure and disrupting the soap structure. Water vapourmixure of soap solution and water vapour creates as a result of this reaction.

The vapor-liquid mixture at 105°C cools down to an average of 83–87°C inside the drying unit, reaching a final temperature of 18–22°C. Due to the heat released during cooling, the remaining moisture in the soap evaporates until the desired humidity level is reached.



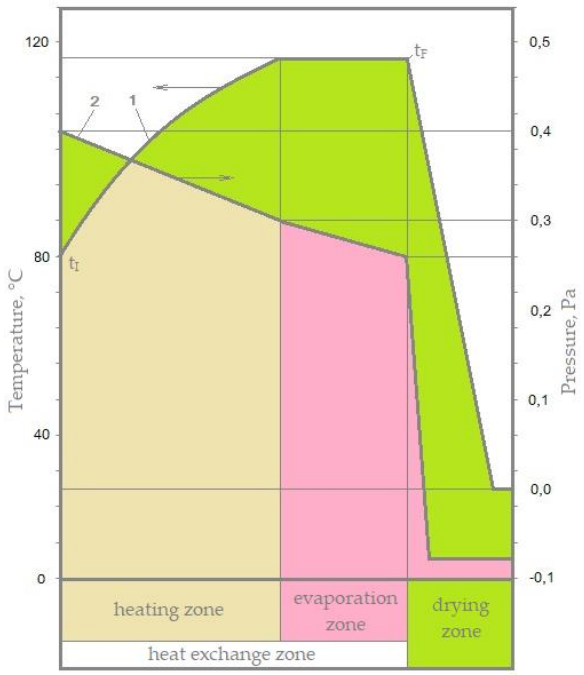
a – Layered model of soap monomers (d – layer thickness, d_a – alkali layer thickness);
b – Lamellar structure encapsulation (1 – layer, 2 – alkali layer);
Figure 2 – Schematic models of the lamellar structure of the soap base.

During drying of soap mixture the following stages occur:

- by heating of soap platelet structure till the inversion phase temperature the transition of liquid crystalline phase into unstable phase take place;
- mechanicaldisintegration of platelet structure as a result of water evaporation from structure and formation of vapour pressure;
- in the low part of device formation of vapour-liquid mixure;
- owing to releasing heat the evaporation of retained water.

Effective temperature mode of boiling-drying device.On the figure 3 the diagram of dried soap mass temperature andinternal pressure change dynamics of platelet structure is shown. From the figure 3 it is seen, that in heating zone of the device the temperature is reached 100-105°C. In this case platelet structure is disintegrated in the device with the decreasing of pressure till 0,2-0,3 Pa. In the evaporation zone of drying device the temperature of soap mass remains constant, but the pressure decrease till 0,1 Pa.

The pressure in the lamellar structure of the soap base inside the drying unit decreases to the residual pressure of water vapor and remains stable within the range of 12–34 mmHg. Under these conditions, the soap base cools down from 105°C to 22°C. Finalmoistureofsoapbasedeterminesthevaluesofitstemperatureandpressure. In case of low moisture value the value of temperature is also low and constantly the water vapour pressure is low too.



1 – Temperature; 2 – Pressure; t_i – Initial temperature;t_f – Final temperature.
Figure 3 – The diagram of temperature and internal pressure change dynamics of platelet structure.

Moisture value of soap mass.The ratio of soap moisture mass to the weight of soap is the value of soap mass moisture.

$$U = 100 \cdot (V/M_S), \%.mass \quad (1)$$

Where:

V – water weight in the soap base, kg/s.

M_s –soap mass yield, kg/s.

The amount of water in the soap is determined using the following equation:

$$V = M_S - M_K - M_G - M_{caus} - M_{salt} \quad (2)$$

Where:

$M_s, M_k, M_g, M_{caus}, M_{salt}$– massyield of soap, fatty acids sodium salts (dry soap), glycerin, alkali, and sodium chloride (table salt), respectively.

In practice the moisture value is determined by:

$$U = 100 - C_S - C_G - C_{caus} - C_{salt}, \% \, mass \quad (3)$$

Where:

$C_S, C_G, C_{caus}, C_{salt}$– weight content of the components in the soap, (% mass).

Sodium salts content in the soap is determined by:

$$C_S = 100 \cdot (M_K/M_S) = C_S \cdot \left(m_{solt}/m_{f.a.}\right) \quad (4)$$

Where:

m_{solt}, $m_{f.a.}$– molecular weight of sodium salt and fatty acids.

Material Balance. The soap initial and final weights are determined by:

$$M_{SI} = M_{SF}[(100 - U_F)/(100 - U_I)] \quad (5)$$

$$M_{SF} = M_{SI}(U_I/U_F) \quad (6)$$

Where:

U_I, U_F– initial and final moisture content of the soap, (% mass).

The total amount of water removed from the soap during drying is calculated by:

$$V_{VSU} = M_{SI}[(U_I - U_F)/(100 - U_F)]$$

Or (7)

$$V_{VSU} = M_{SF}[(U_I - U_F)/(100 - U_I)]$$

The water content self-evaporated in the drying device is calculated by:

$$V_{VCK} = M_{SI} G_{RMP}(t_I - t_{VCK})/r_{VSK} \quad (8)$$

Where:

G_{RMP}–soap base and water vapor mixture specific thermal capacity at the output of the drying device, J/kg -K).

t_I, t_{VSK}– soap temperature before entering the drying device and inside the device °C.

r_{VSK}– specific heat of vaporization in the drying unit, J/kg.

Water content evaporated from soap mass in the drying device is calculated by:

$$V_R = V_{VSU} - V_{VSK} \quad (9)$$

Thermal Balance. The heat consumption for heating and partial evaporation of the soap base in the drying device is calculated by:

$$Q = M_{SI} C_{SB}(t_F - t_I) + V_R r_g \quad (10)$$

Where:

t_i, t_f– initial and final temperatures, °C.

C_{SB}– soap bass specific thermal capacity, J/(kg·K).

r_g– specific heat of evaporation in the evaporation zone of the drying unit, J/kg.

The consumption of heating steam in the drying device is determined by:

$$G_{HS} = Q/(r_{HS} s) \quad (11)$$

Where:

r_{HS}- specific heat of condensation of heating steam, J/kg.

s – dryness fraction of heating steam (0.95).

Conclusion

A model of the drying process mechanism for the soap base obtained from used cooking oil residues in the integrated boiling and drying unit was developed. On the basis of research results of soap base physical-chemical structure and phase composition the presented model mechanism was obtained. The temperature mode of drying process was established. The temperature of soap bass in the heating zone of the apparatus increases from 80°C to 105°C and remains at this level during the process of evaporation. Then the soap base is cooled on

83°C (from 105°C to 22°C), and in this case water residues is removed due to heat released during cooling. The equation of material and thermal balance for the processes of drying and evaporation are suggested.

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ҚОЛДАНЫЛҒАН ТАҒАМДЫҚ МАЙ ҚАЛДЫҚТАРЫНҚАЖЕТКЕ ЖАРАТУ ЖОЛЫМЕН АЛЫНҒАН САБЫН НЕГІЗІН КЕПТІРУДІҢ ТЕМПЕРАТУРАЛЫҚ ТӘРТІБІ МЕН МЕХАНИЗМІ

Аңдатпа. Қолданылған тағамдық май қалдықтарының санитарлық гигиеналық тазалық өнімдерін алуда қайталама шикізат ретінде қолданылу мүмкіндігі сипатталған. Гигиеналық сабын негізін кептіру механизмінің моделы және температуралық тәртіптерін зерттеу нәтижелері ұсынылған. Натрийлі сабын негізін кептіру механизмінің модельдік конструкциясы мен сабын құрамының физика-химиялық құрылымы және фазалық құрамын қарастыруға негізделген кептіру үрдісінің температуралық тәртібі қарастырылды.

Қолданылған тағамдық май қалдықтарынан дәретханалық сабын алу мысалында кешенді қайнату және кептіру қондырғысының сұлбасы ұсынылған. Ламеллярлы құрылымды сабын негізін кептіру нәтижесінде ылғалды жою механизмінің сұлбасы келтірілген. Кешенді қайнату және кептіру қондырғысының температуралық тәртібін зерттеу нәтижелері ылғалдылықтың төмендеуімен температураның төвен болуы шарт және сәйкесінше қалдық бу қысымының да төмен болатынын көрсетті. Қолданылған тағамдық май қылдықтарынан дәретханалық сабын өндіру үрдісінің материалдық және жылулық баланс теңдеулері келтірілген. Ұсынылған зерттеу нәтижелері жалпы түзілетін тағамдық май қалдықтарын екіншілей шикізат ретінде қолданып, қызмет көрсету саласы үшін санитарлық гигиеналық сабын алу өндірісінде қолдану жоспарлануда.

Кілт сөздер: экологиялық ауыртпалық; қоршаған орта; тағамдық май қалдықтары; екіншілей шикізат; қажетке жарату; қайта өңдеу; сабын негізі; кептіру механизмі; температуралық тәртіп; материалдық баланс;жылулық баланс.

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ТЕМПЕРАТУРНЫЙ РЕЖИМ И МЕХАНИЗМ СУШКИ МЫЛЬНОЙ ОСНОВЫ, ПОЛУЧЕННОЙ ПУТЕМ УТИЛИЗАЦИИ ОТХОДОВ ПИЩЕВОГО МАСЛА

Аннотация. Описана возможность использования отходов отработанного пищевого масла в качестве вторичного сырья при производстве санитарно-гигиенических моющих средств. Представлена модель механизма сушки гигиенической мыльной основы и результаты исследования температурных режимов. Рассмотрены модельные построения механизма сушки натриевой мыльной основы и температурного режима процесса сушки на основе учета физико-химической структуры и фазового состава мыльной композиции.

Представлена схема комплексной варочно-сушильной установки на примере производства туалетного мыла из отходов отработанного пищевого масла. Представлена схема механизма удаления влаги в результате сушки мыльной основы с ламеллярной структурой. Результаты исследования температурного режима работы комплексной варочно-сушильной установки показали, что при снижении влажности температура должна быть минимальной и, соответственно, остаточное давление паров также будет ниже. Представлены уравнения материального и теплового баланса для процесса производства

туалетного мыла из отходов отработанного кулинарного масла. Результаты предлагаемых исследований планируется использовать при производстве санитарно-гигиенического мыла для сферы услуг, используя в качестве вторичного сырья отходов кулинарного масла.

Ключевые слова: экоологическая нагрузка; окружающая среда; отходы кулинарного масла; вторичное сырье; утилизация; переработка; мыльная основа; механизм сушки; температурный режим; материальный баланс; тепловой баланс.