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EQUIPMENT FOR THE PRODUCTION OF SOFT SEAMLESS GELATIN CAPSULES IN THE FOOD INDUSTRY: A COMPARATIVE ANALYSIS OF DROPLET AND SPRAY-DRYING METHODS

Abstract: *This paper presents a comparative analysis of the two primary technologies for producing soft seamless gelatin capsules – droplet (coaxial) and spray-drying (spray-drying microencapsulation) methods – as applied to the needs of the food industry and nutraceuticals. The structural features of the equipment, key process parameters (capsule size and shape, shell composition, dosing accuracy, productivity), and application areas for each technology are described. Based on a review of technical documentation, scientific publications, and pharmacopeial standards (USP, EP), the advantages and limitations of both methods are identified: the droplet method provides high dosing accuracy and an aesthetically pleasing appearance of large spherical capsules with liquid cores, whereas spray-drying enables mass production of microcapsules for bulk food blends and maintains the stability of sensitive ingredients. Conclusions are drawn regarding the appropriateness of each method depending on the type of active ingredient, required production volume, and storage conditions. Potential future developments – such as new shell materials and gentler drying regimes – are also outlined.*

Key words: *seamless gelatin capsules; droplet method (coaxial encapsulation); spray-drying (microencapsulation); food supplements and nutraceuticals; dosing accuracy; microcapsules; functional products.*

Soft Seamless Gelatin Capsules are uniform spherical shells made of gelatin filled with a liquid core, without any seams or joints. Due to the absence of seams, such capsules are referred to as “seamless”; they are usually transparent or colored, elastic, and contain a measured dose of oil or another liquid inside [1]. In the food industry and nutraceuticals, seamless capsules are widely used for the encapsulation of vitamin oils (e.g., omega-3 from fish oil), fat-soluble vitamins (A, D, E, K), and flavor additives – this allows for masking the unpleasant taste or smell of ingredients and protects them from oxidation [2]. Additionally, seamless encapsulation technology is applied in the development of **functional products** – for example, capsules with peppermint oil are used in chewing gums and confectionery, while microcapsules with probiotics are added to food products to enhance their health benefits. This article focuses on equipment for producing seamless gelatin capsules in the context of the food industry – primarily comparing two encapsulation methodologies (droplet and spray methods), their design features, and the resulting capsule properties.

Introduction. Between 2021 and 2025, there has been growing interest in encapsulation technologies in the food sector, driven by several key factors. Firstly, there is an increasing demand for functional food additives and biologically active compounds that require hermetic packaging of active substances. The global gelatin and capsule market has shown steady growth: according to industry analysts, global gelatin consumption was valued at $6.7 billion in 2022 and is projected to reach $8.5 billion by 2027 [3]. In parallel, the capsule industry is also expanding – the market for empty capsules (for pharmaceuticals and nutraceuticals) may reach $3.2 billion by 2027, with an average annual growth rate of ~7.4% [4]. These trends reflect the growing need among producers of dietary supplements and functional foods for modern encapsulation technologies.

Secondly, active research and development are being conducted to improve materials and encapsulation methods. Despite the emergence of plant-based gelatin alternatives (such as cellulose-based materials), gelatin capsules continue to dominate due to their low cost and excellent consumer properties. At the same time, encapsulation methods themselves are evolving: the relatively new droplet method (also known as the «bubble method»), introduced in the 1960s, has significantly improved dosing capabilities in recent years – the maximum fill volume of a seamless capsule has increased from ~0.3 ml to 0.75 ml thanks to advancements by researchers in Japan and Israel [5, 7]. Simultaneously, spray drying and other microencapsulation techniques have become well-established in the food industry as cost-effective methods of protecting sensitive components (such as vitamins, flavorings, and probiotics) from external influences. The combination of these factors makes the topic of selecting and comparing equipment for seamless encapsulation particularly relevant for modern food manufacturing [6, 8].

Despite the emergence of plant-based gelatin analogues, gelatin capsules continue to dominate due to their low cost and excellent consumer characteristics [9]. Spray drying and other microencapsulation techniques have firmly established themselves in the food industry as economical methods for protecting sensitive components (vitamins, flavorings, probiotics) from external factors [10]. The combination of these factors makes the topic of choosing and comparing equipment for seamless encapsulation highly relevant to today's food production.

Methods and Methodology. Two fundamentally different approaches are used in the industry for producing seamless gelatin capsules: droplet encapsulation (coaxial droplet formation) and spray encapsulation (microencapsulation via spray drying).

1. **Droplet Encapsulation (Coaxial Droplet Formation).**
   - Review of patents and technical specifications of equipment in accordance with USP and European Pharmacopoeia recommendations [11, 12].
   - Analysis of key operating parameters: gelatin temperature, core flow rate, cooling conditions.
   - Compilation of a comparative parameter table.
2. **Spray Encapsulation (Spray Drying).**
   - Examination of technological guidelines from microencapsulation equipment manufacturers.
   - Analysis of emulsion systems used for shell materials.
   - Evaluation of economic and energy efficiency parameters of the process.

This study utilized scientific literature and technical documentation from 2021-2025, as well as USP 43–NF 38 and EP 10 standards [11, 12].

Droplet method («bubble method»). This method is based on the formation of gelatin capsules using a coaxial droplet generator, from which the shell and the liquid core are simultaneously extruded. A special dual-channel nozzle produces a **two-phase droplet**: the outer layer consists of molten gelatin, while the inner one contains the filler liquid. Due to surface tension forces, the droplet self-forms into a perfect sphere, "sealing" the core without any seams. The capsule then passes through a cooling medium (usually chilled vegetable oil), where the gelatin shell rapidly solidifies and retains its spherical shape The equipment used for the droplet method includes several main components: a tank with heated gelatin mass, a container with the liquid filler, a coaxial encapsulation head, a cooling oil delivery system (with a pump and chiller unit), and a control system for dosing and temperature regulation. One of the encapsulator models is shown below in Figure 1, featuring a vertical **cooling column** (transparent tube) in which capsules are formed and solidified:

Fig. 1 – Encapsulator

Design of a typical encapsulator for seamless capsules (droplet method): the transparent cooling column, electronic control panel, and stainless steel body are visible. The production process on such equipment is continuous: the gelatin mass is maintained at a temperature of approximately 60-70 °C, the filler is supplied cooled (12-40 °C), and the cooling oil circulates in a closed loop at 5-10 °C to ensure rapid shell gelation. The droplet formation frequency is adjustable (typically 1-5 pulses per second per nozzle) to control capsule size. Modern encapsulators are equipped with PLC controllers and touchscreen panels, which allow for precise temperature control and synchronization of shell/core feeding. As a result, the droplet method yields **soft gelatin spheres with diameters** ranging from ~2 mm to 10-15 mm, with a very narrow mass variation – dosage deviations usually do not exceed ± 3%. Capsules are generally filled with **hydrophobic liquids** such as vegetable oils, oil-based vitamin solutions, fish oil, and oil-based aromatic essences. This is because the gelatin shell comes into contact with water during formation and must remain insoluble; therefore, direct encapsulation of aqueous fillers using this method is difficult. After formation, the capsules are washed from the oil medium, dried for 1-2 days, and packaged.

Spray-drying method. The term **«spray-drying»** typically refers to a technology widely used for microencapsulation of food ingredients. The core concept of the method is as follows: a liquid emulsion containing both the core material and the shell-forming agent is atomized into a stream of hot air. The fine droplets dry almost instantly, and a powder of microcapsules is collected at the outlet. In spray-drying, the shell material often consists of **gelatin blended with polysaccharides** – such as gelatin combined with maltodextrin, gum arabic, or modified starch. These combinations enable the formation of a solid matrix around the core during the drying process. Prior to spraying, the core (active ingredient) is typically emulsified in the shell solution to ensure even distribution of oil droplets within the capsules or uniform incorporation of a hydrophilic component A schematic diagram of the spray-encapsulation process is shown in Figure 2:

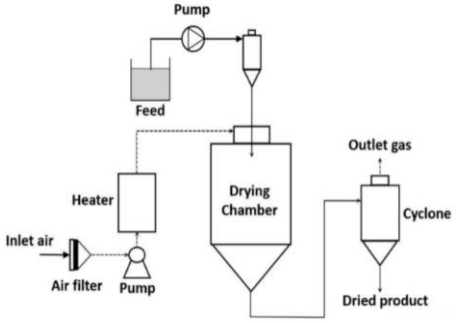

Fig. 2 – Diagram of a Spray Drying System for Microcapsule Production

Diagram of a spray-drying setup for producing microcapsules. A liquid feed solution is pumped through a nozzle at the top of the drying chamber. Simultaneously, heated dry air (inlet air) is introduced via an atomizing nozzle. The tiny droplets instantly dry in the air stream; the resulting powder particles settle downward and are collected through a cyclone separator as the final dry product (dried product), while the used moist air exits through an exhaust (outlet gas).

Spray-drying equipment includes a feed **tank for the initial emulsion**, a pump, and an atomizing nozzle, which can be either a high-pressure nozzle or a centrifugal atomizer disc. **The drying unit** consists of a vertical chamber (drying tower), into which hot air (typically 150–200 °C) is introduced. A separation system – either a cyclone or a filter – is used to collect the dried microcapsules. In industrial applications, both small laboratory-scale spray dryers (with a capacity of 1–5 liters of emulsion per hour) and large-scale units capable of processing up to approximately 100 liters per hour are available. Process parameters are selected according to the characteristics of the product: the inlet temperature must be high enough for rapid drying, but not excessive so as to avoid degrading bioactive substances. The outlet air temperature is controlled to regulate the residual moisture of the powder. The final microcapsules are obtained as a **dry powder**. The particles are spherical or slightly irregular in shape, with sizes ranging from approximately 10 μm to several hundred micrometers. Each particle contains the encapsulated substance (e.g., oil droplets, aromatic compounds, vitamins, etc.) dispersed in a dried polymer matrix [4]. Thus, unlike the drop-based method, spray-drying does not produce individual large capsules but yields a bulk powder consisting of **numerous microcapsules.**

Results. Based on the analysis of literature and equipment specifications, the key differences between drop-form encapsulators and spray-drying microencapsulation systems are summarized in Table 1.

Table 1 – Comparison of Encapsulation Methods

Parameter	Drop Method (Seamless Soft Capsules)	Spray-Drying Method (Microcapsules)
Capsule size and shape	Spherical capsules with a diameter of 2-10 mm (up to 15 mm in some cases). Perfectly round shape due to the surface tension of gelatin.	Microcapsules with diameters from ~10 μm to several hundred microns. The shape is close to spherical; agglomeration may occur in the powder.
Shell materials	Gelatin (bovine, porcine, or fish) with a plasticizer (glycerin, sorbitol) – forms an elastic gel-like shell. Solidifies upon cooling.	Polymer combinations (gelatin, gum arabic, maltodextrin, starch, etc.). The shell forms during drying, transitioning from liquid to a solid matrix.
Type of encapsulated core	Liquids immiscible with water: oils, fat-soluble vitamin solutions, oil-based extracts. Aqueous solutions and suspensions are not used (they break down gelatin).	Broad range of substances: oils and aromatic compounds (emulsified within the emulsion), as well as water-soluble ingredients (vitamins, extracts), suspensions, and even live cultures (probiotics) combined with a carrier.
Productivity	15,000-60,000 capsules per hour, depending on the model and capsule size. For example, a 2-nozzle encapsulator produces ~20 capsules/sec with a 3-4 mm diameter.	Very high (measured by mass, not individual units): large spray dryers can process 50-100 liters of emulsion per hour, yielding tens of kilograms of microcapsules. The process is continuous, limited by dryer capacity and feed rate.
Dosing accuracy	High: filler mass deviation is no more than ±2-5% due to the consistency of droplet size. Each capsule contains a precisely dosed liquid core (~0.3-0.75 ml).	Difficult to assess per microcapsule due to the bulk nature of the product. Total yield and encapsulation efficiency are more relevant: typically 80-95% of the active ingredient is encapsulated. Losses may occur (material sticking to dryer walls or remaining on particle surfaces).
Equipment features	Includes units for gelatin melting, core dosing, coaxial nozzles, a cooled column or bath, a circulating cooling oil system, and drying chambers. Requires sterile conditions and precise temperature control. A compact line weighs ~200-1000 kg.	Includes a spray system (nozzle or centrifuge), a drying tower several meters high, an air heater, and a cyclone for powder collection. Larger footprint; requires dehumidification and dust removal systems. Precise control of parameters (temperature, air flow) is critical to product quality.
Applications	Nutraceuticals and pharmaceuticals: capsules with fish oil, vitamins, and aromatic oils for oral use; food products: e.g., floating «caviar-like» capsules in drinks and desserts (if made with agar/alginate), flavor capsules for tea. Also used in the tobacco industry – menthol capsules for cigarette filters.	Widely used in the food industry: powders with encapsulated flavors (for soups, beverages), dairy products (fortified dry blends), baby food (microcapsules with Omega-3 in cereals), baked goods and confectionery (bake-stable flavor powders). Also for probiotic formulations, dry spices with protected essential oils, etc.

As shown in Table 1, the **drop method** provides large, individually dosed capsules that are convenient for personal consumption – similar to traditional soft gel capsules, but seamless. These capsules are characterized by high filling accuracy and an attractive appearance («pearls» with a liquid core); however, their application is limited to oily liquids. In contrast, the **spray-drying method** is more versatile in terms of encapsulated substances and offers higher productivity. It is suitable for large-scale production of microcapsules, which can then be blended with other dry ingredients. A drawback of spray-drying is the multi-stage nature of the process and the need for careful control of drying conditions to preserve the activity of sensitive components (e.g., vitamins may partially degrade at high temperatures). Moreover, microcapsules are in powder form and are incorporated

into products as part of a mixture, whereas drop-formed capsules can be consumed individually as stand-alone dosed units (e.g., fish oil capsules). Thus, each method has found its niche in the food industry: drop encapsulation is used in the production of dietary **supplements and functional products for consumers**, while spray microencapsulation is used in **ingredient technology** (such as creating fortified powders, premixes, etc.).

Seamless gelatin capsules have firmly established themselves in the food industry and related sectors due to their ability to protect, dose, and mask various active substances. The analysis shows that two distinct approaches are used for their production, each with its own advantages **Drop-type encapsulators** produce relatively large, precisely dosed spherical capsules, ideal for **dietary supplements** and products requiring individual dosing and an appealing appearance. These capsules ensure high bioavailability of ingredients and enhance consumer properties (no unpleasant taste, ease of consumption). On the other hand, **spray dryers** and associated microencapsulation technologies are indispensable for processing large volumes of raw material and embedding active components into complex food matrices. Spray-dried microcapsules are easy to dose when mixing, stable during storage and transportation, and capable of delivering controlled release of flavors and nutrients in the final product. In the future, further improvements are expected for both methods: for the drop method – expanding the range of encapsulated substances (possibly through new gelling materials resistant to water); for the spray method – implementing gentle drying modes (e.g., using vacuum or lyophilization) for especially sensitive bioactive compounds. Today, equipment manufacturers already offer comprehensive solutions – from emulsion preparation to automated drying and capsule packaging – reflecting the high level of technological maturity. **Thus, equipment for seamless gelatin capsules has become an integral part of modern food production, enabling the creation of new products with improved consumer properties and preserving the value of unstable ingredients.** Competition and innovation in this field will continue to drive the development of more efficient and flexible encapsulation methods, opening up new opportunities for the food industry.

Conclusion. The conducted analysis has shown that the choice of encapsulation method is determined by the following factors:

- The required size and form (individually dosed capsules vs. powder-form microcapsules).
- The type of active substance (oil-based solutions vs. hydrophilic components and live cultures).
- Production volumes and economic feasibility.
- Stability and quality control requirements (USP and EP standards) [11, 12].

In the future, further improvements of both methods are expected: expansion of the range of shell materials for the drop-based method, and implementation of gentle spray-drying modes (vacuum drying, lyophilization) for especially sensitive compounds [5]. Competition and innovation in seamless encapsulation equipment will continue to drive the development of more efficient and flexible solutions, opening new opportunities for the food industry.

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ТАҒАМ ӨНЕРКӘСІБІНДЕ ЖҰМСАҚ ШВСІЗ ЖЕЛАТИНДІ КАПСУЛАЛАРДЫ АЛУ ЖАБДЫҚТАРЫ: ТАМШЫЛАТЫП ЖӘНЕ ШАШЫП КЕПТІРУ ӘДІСТЕРІНІҢ САЛЫСТЫРМАЛЫ ТАЛДАУЫ

Бұл мақалада тағам өнеркәсібі мен нутрицевтикадағы жұмсақ жіксіз желатинді капсулаларды өндірудің екі негізгі технологиясы – тамшылатып (коаксиалды) және шашып кептіру (спрей-сушка) – салыстырмалы түрде талданады. Әр әдістің аппаратуралық ерекшеліктері, процестің негізгі параметрлері (капсулалардың өлшемі мен формасы, қабат құрамының сапасы, доза дәлдігі, өнім шығарымдылығы) және қолдану салалары сипатталады. Техникалық құжаттама, ғылыми басылымдар және фармакопея стандарттары (USP, EP) негізінде өткізілген шолу нәтижесінде: тамшылатып әдіс ірі, сұйық ядролы сфералық капсулаларды жоғары дәлдікпен дозалау мен эстетикалық тұрғыдан тартымды етуге мүмкіндік берсе, шашып кептіру микрокапсулаларды ұнтақтық қоспаларға жаппай енгізуге және сезімтал компоненттердің тұрақтылығын қамтамасыз етуге қолайлы екені анықталды. Әдісті таңдау актив зат түріне, өндіріс көлеміне және сақтау шарттарына байланысты жүзеге асырылуы тиіс. Сонымен қатар, келешекте жаңа қабаттық материалдар мен жұмсақ кептіру режимдерін (вакуумды спрей-сушка, лиофилизация) енгізу арқылы технологияларды жетілдіру перспективасы көрсетілген.

Түйін сөздер: *жіксіз желатинді капсулалар, тамшылатып әдіс (коаксиалды капсулалау), шашып кептіру (микрокапсулалау), тағамдық қоспалар мен нутрицевтика, доза дәлдігі, микрокапсулалар, функционалдық өнімдер.*

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ОБОРУДОВАНИЕ ДЛЯ ПОЛУЧЕНИЯ МЯГКИХ БЕСШОВНЫХ ЖЕЛАТИНОВЫХ КАПСУЛ В ПИЩЕВОЙ ПРОМЫШЛЕННОСТИ: СРАВНИТЕЛЬНЫЙ АНАЛИЗ КАПЕЛЬНОГО И РАСПЫЛИТЕЛЬНОГО МЕТОДОВ

В статье представлен сравнительный анализ двух основных технологий получения мягких бесшовных желатиновых капсул – капельного (коаксиального) и распылительного (спрей-сушка) методов – применительно к потребностям пищевой промышленности и нутрицевтики. Описаны конструктивные особенности оборудования, ключевые параметры процесса (размер и форма капсул, состав оболочки, точность дозирования, производительность) и области использования каждой технологии. На основе обзора технической документации, научных публикаций и фармакопейных стандартов (USP, EP) выделены преимущества и ограничения обоих методов: капельный метод обеспечивает высокую точность дозировки и эстетичный вид крупных сферических капсул с жидким ядром, а распылительная сушка – массовое производство микрокапсул для сыпучих пищевых смесей и обеспечение стабильности чувствительных компонентов. Сделаны выводы о целесообразности выбора метода в зависимости от типа активного вещества, требуемого объёма производства и условий хранения, а также обозначены перспективы развития

технологий (новые оболочковые материалы, щадящие режимы сушки). На основе обзора научной литературы, технической документации и фармакопейных стандартов сделаны выводы о преимуществах и ограничениях каждого метода, а также даны рекомендации по выбору технологии в зависимости от типа активного вещества, объёмов производства и требований к стабильности продукта.

***Ключевые слова**: бесшовные желатиновые капсулы, капельный метод (коаксиальное капсулирование), распылительная сушка (микрокапсулирование), пищевые добавки и нутрицевтика, точность дозирования, микрокапсулы, функциональные продукты.*

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