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TUNNEL DEHYDRATOR FOR LOW GLYCEMIC INDEX FLAKES: TECHNOLOGICAL FEATURES, ENERGY EFFICIENCY, AND PRODUCT QUALITY

ТУНЕЛЬНИЙ ДЕГІДРАТОР ДЛЯ ПЛАСТИВЦІВ З НИЗЬКИМ ГЛІКЕМІЧНИМ
ІНДЕКСОМ: ТЕХНОЛОГІЧНІ ОСОБЛИВОСТІ, ЕНЕРГОЕФЕКТИВНІСТЬ ТА
ЯКІСТЬ ПРОДУКЦІЇ

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Annotation. The tunnel dehydrator represents a cutting-edge, energy-efficient solution for drying food products, particularly in the production of low-glycemic-index flakes. This innovation plays a crucial role in addressing the growing issues of diabetes and obesity by enabling the creation of foods that help stabilize blood glucose levels. This study examines the structural features of the dehydrator, highlighting its advantages over traditional drum dryers. It also evaluates the uniformity of drying and assesses the economic feasibility of its implementation. By utilizing zonal heating and controlled air circulation, the system ensures even moisture removal while preserving carbohydrate structure and minimizing nutrient loss. The findings of this research contribute to optimizing the dehydrator's operating parameters and provide practical recommendations for its integration into the food industry.

Keywords: tunnel dehydrator, dehydration, food drying, low glycemic index flakes, energy efficiency, drying uniformity, controlled air circulation, nutrient preservation, food industry, drying technology

Introduction

Modern food production demands efficient and energy-saving dehydration methods that preserve the nutritional value, texture, and sensory qualities of products. Drying plays a crucial role in manufacturing confectionery, functional foods, and snacks, where moisture stability is key to maintaining product quality. A growing focus has been placed on technologies for producing low-glycemic-index flakes—an essential component in the fight against diabetes and obesity. These products help regulate blood glucose levels and promote healthier eating habits.

Traditional drying methods, such as drum dryers, present several limitations, including uneven drying, high energy consumption, and potential degradation of



nutritional value due to intense heat exposure. To address these challenges, a tunnel dehydrator has been developed, designed specifically for producing low-glycemic-index flakes and other functional food products. This dehydration technology relies on zonal heating and controlled air circulation, ensuring uniform moisture removal and optimal energy efficiency while preserving biologically active components and the natural structure of carbohydrates.

This study aims to assess the efficiency of the tunnel dehydrator, compare its advantages over conventional drying methods, and optimize its operational parameters to enhance the quality of the final product. The research examines the structural features of the dehydrator, evaluates the consistency of drying, conducts an economic analysis of energy consumption and production profitability, and explores the impact of this technology on texture, taste, and nutritional properties. The findings will help refine the dehydrator's performance parameters and provide recommendations for its integration into the food industry, contributing to the production of healthier foods that support the fight against metabolic disorders.

1.1. Relevance of the Study

The modern food industry faces an urgent need to refine dehydration technologies. As one of the primary methods of food preservation, dehydration extends shelf life, retains nutritional value, and enhances texture. With the rising demand for healthier, low-glycemic-index products, the need for more efficient drying technologies has become increasingly pressing [1].

Traditional drying methods, particularly drum dryers, often lead to the partial loss of biologically active compounds, reducing the final product's nutritional quality. Additionally, inadequate control over dehydration parameters can negatively impact taste and texture [2]. This issue is especially critical in the confectionery industry, where texture and sensory properties play a key role in shaping consumer preferences.

Limitations of Traditional Dehydration Methods (Drum Dryers) and Their Impact on Product Quality

Drum dryers are widely used in the production of dry food products, including cereal flakes and dried fruits. However, this method has several significant drawbacks:



- Uneven drying. Products in direct contact with the heated drum tend to overdry, while inner layers may retain excess moisture. This inconsistency affects both texture uniformity and overall product quality [3].
- High energy consumption. Drum dryers require substantial amounts of thermal energy, leading to increased production costs [4].
- Clumping and sticking issues. Elevated temperatures can cause partial caramelization of carbohydrates or lead to the formation of hardened lumps, complicating further processing.
- Limited raw material compatibility. Drum dryers are unsuitable for heat-sensitive products, as excessive temperatures can alter their chemical composition and sensory characteristics [2].

These limitations drive manufacturers to seek alternative dehydration technologies that offer more uniform heat distribution, lower energy consumption, and better texture preservation, ultimately improving product quality and production efficiency.

The Importance of Tunnel Dehydrators in Enhancing Confectionery Quality

One of the most advanced and effective drying methods available today is the tunnel dehydrator, which ensures more uniform and controlled moisture removal. Its operation is based on convective heating, allowing for the gradual extraction of moisture while minimizing the risk of thermal damage [5].

Key Advantages of Tunnel Dehydrators Over Drum Dryers

- Consistent drying. The product moves along a conveyor belt through zones with controlled temperature and airflow, ensuring even dehydration.
- Lower energy consumption. The combination of convective and infrared heating helps reduce heat loss, making the process more efficient.
- Improved sensory properties. Unlike drum drying, tunnel dehydration prevents over-drying and the formation of clumps, preserving the product's texture.
- Versatile raw material processing. Tunnel dehydrators are suitable for drying cereals, fruits, vegetables, and protein-based products, making them ideal for confectionery applications [2].



Thanks to these features, tunnel dehydrators significantly enhance the quality, texture, and nutritional profile of confectionery products. With growing consumer demand for healthier snacks free from artificial preservatives and added sugars, advanced dehydration technologies are becoming a key factor in maintaining competitiveness in the food industry [1].

1.2. Aim and Objectives of the Study

Modern dehydration technologies play a crucial role in the food industry, ensuring product quality, extending shelf life, and improving texture. The choice of drying method significantly impacts the final product's characteristics and, consequently, its consumer appeal. The tunnel dehydrator presents a promising alternative to conventional drum dryers, offering precise control over drying parameters, ensuring uniform moisture removal, and optimizing product texture.

The primary goal of this article is to examine the technological features of the tunnel dehydrator and evaluate its advantages over traditional drying methods.

To achieve this goal, the study focuses on the following key objectives:

- Analyzing the technological aspects of tunnel dehydration. This involves examining the dehydrator's design, operating principles, and critical parameters affecting dehydration efficiency. Particular attention is given to the multi-zone drying system, which allows for precise regulation of temperature and airflow at different stages of the process.
- Assessing its advantages over traditional drying methods. A comparative analysis will be conducted to evaluate energy consumption, drying uniformity, sensory characteristics, ease of maintenance, and overall economic feasibility of tunnel dehydrators versus drum dryers.
- Investigating the impact of dehydrator design and process conditions on the final product. This includes examining how moisture content, texture, taste, and nutritional value are influenced by tunnel dehydration. The study will also explore how specific drying parameters—such as temperature, airflow speed, and infrared heating—affect the composition of the final product and whether this method can help maintain a low glycemic index in finished goods.



Ultimately, the findings of this research will contribute to optimizing the operational parameters of tunnel dehydrators and developing recommendations for their effective integration into the food industry.

2. Review of Modern Research

2.1. Contemporary Dehydration Methods in the Food Industry

Dehydration plays a crucial role in the food industry, helping preserve products, reduce their weight and volume, and extend shelf life. However, different drying techniques have their own strengths and limitations, which directly impact the quality of the final product [6].

One of the most widely used methods is drum drying, commonly applied in the production of flakes, powdered foods, and semi-finished products. In this process, the product is spread onto the heated surface of a rotating drum, facilitating moisture evaporation [7].

Advantages of Drum Dryers:

- High processing capacity, making them suitable for large-scale production.
- Relatively low operational costs.
- Compatibility with a wide range of products, including dairy powders, fruit purées, and starch-based foods.

Disadvantages of Drum Dryers:

- Uneven drying, as variations in product layer thickness can lead to inconsistencies.
- High temperatures may cause thermal degradation of proteins and caramelization of sugars, altering both taste and nutritional value [8].
- Energy-intensive operation requiring frequent maintenance.

An alternative to drum drying is vacuum drying, which operates under reduced pressure, lowering the evaporation temperature. This minimizes thermal damage and helps retain biologically active compounds such as vitamins and antioxidants [9].

Infrared drying utilizes electromagnetic radiation to transfer heat deep into the product, promoting faster and more uniform moisture removal. While this method is energy-efficient and time-saving, it requires precise temperature control, as excessive radiation



can lead to overheating [10].

Freeze-drying (sublimation drying) is considered one of the most effective methods for preserving nutritional quality, as it occurs in three stages: freezing, sublimation, and desorption of residual moisture. This technique helps maintain the original structure of the product while preserving its nutritional value [11]. However, high costs and significant energy demands limit its widespread application.

2.2. Glycemic Index and Dehydration

The glycemic index (GI) measures the rate at which carbohydrates are absorbed and affect blood glucose levels after consumption. Dehydration methods can significantly alter this parameter, as heat treatment impacts the structure of starches, proteins, and sugars in food products [12].

Studies indicate that intensive thermal processing during drum drying can increase GI due to starch gelatinization, making it more accessible to digestive enzymes [13]. In contrast, vacuum and freeze-drying better preserve starch structure, potentially leading to a slower rise in blood glucose levels after consumption [14].

Additionally, combining dehydration with dietary fiber or protein enrichment can further reduce GI, as fibers slow down starch digestion, while proteins moderate glycemic response [15].

2.3. Alternative Dehydration Technologies and Their Potential

Given the limitations of traditional drying methods, recent research has focused on combining different dehydration techniques to improve efficiency and product quality. For instance, integrating infrared heating with vacuum drying has been shown to shorten drying time, minimize thermal degradation, and enhance final product quality [16].

The advancement of electromagnetic drying and ultrasound-assisted dehydration opens new possibilities for reducing energy consumption and achieving more uniform drying [17]. Additionally, energy-efficient hybrid technologies, such as convection drying combined with infrared or microwave heating, are being actively explored to accelerate moisture removal while preserving product structure [18].

Thus, the development of combined and energy-efficient dehydration methods is



a key direction in food technology innovation, allowing manufacturers to optimize production processes and enhance the nutritional properties of final products.

3. Materials and Methods

3.1. Structural Features of the Tunnel Dehydrator

During the development of the tunnel dehydrator (Figure 1) for confectionery flake production, I designed a system that integrates modern heating and drying technologies. The primary objective was to create an efficient dehydration system that ensures uniform moisture removal while enhancing the sensory characteristics of the final product.

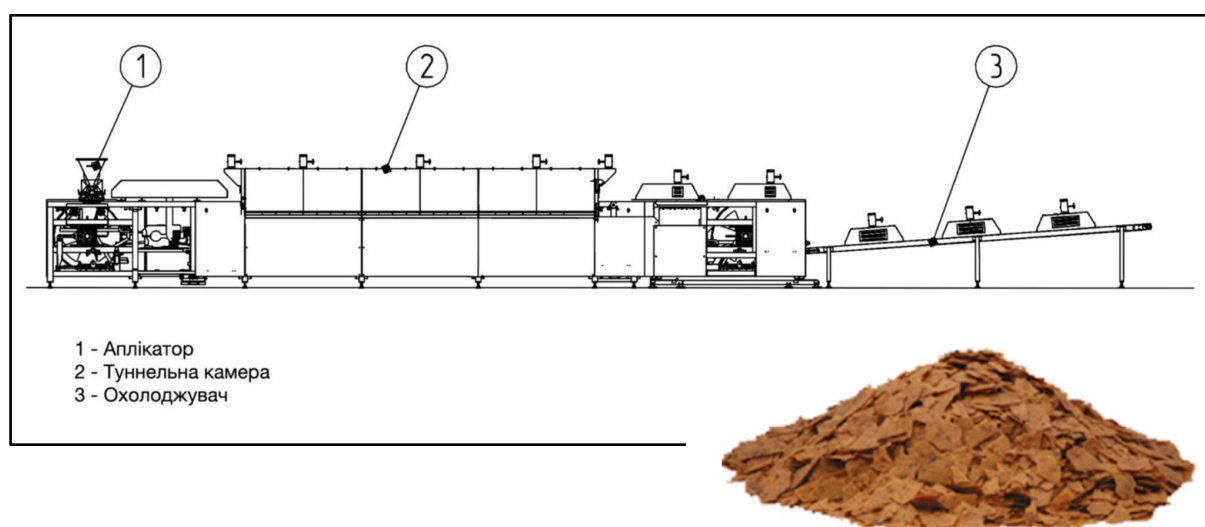


Figure 1 – General schematic of the tunnel dehydrator.

Description of the Technological Process

1. The ground mixture is fed into the applicator (1), which evenly spreads a thin layer onto the steel conveyor belt.
2. The thin layer of the mixture passes through specialized heating zones, where moisture is gradually removed.
3. The dried sheet is then cooled to a brittle state before undergoing further crushing.

Tunnel Dehydrator Description (Figure 2)

The tunnel dehydrator consists of a steel conveyor belt that moves through three heating zones, each equipped with adjustable temperature and airflow intensity controls. This design ensures optimal drying conditions for the product.



The first stage of the process involves feeding the ground mixture into the applicator, which evenly distributes it onto the steel belt. The thin layer then moves sequentially through the three controlled heating zones, ensuring efficient and uniform dehydration.

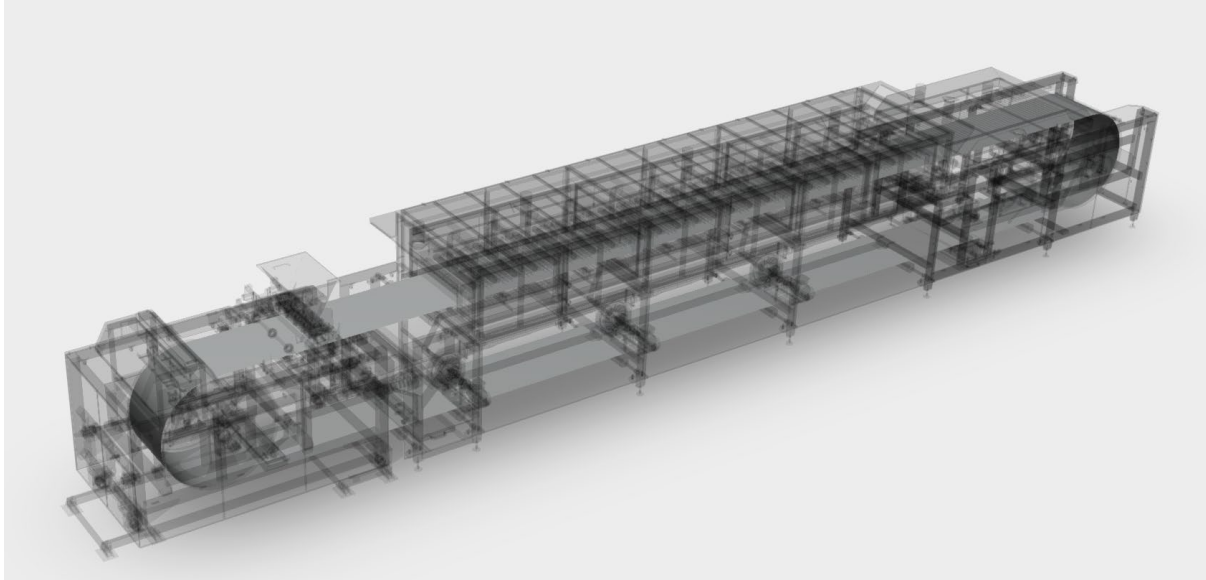


Figure 2 – 3D Model of the Tunnel Dehydrator.

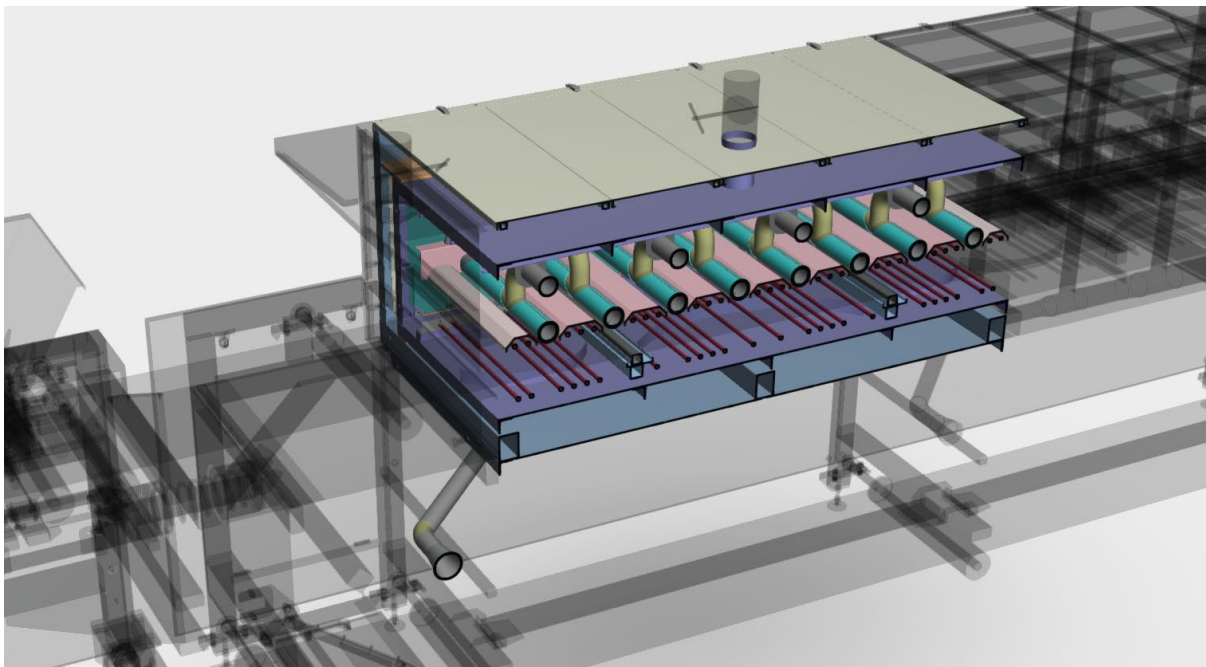


Figure 3 – Heating and Convection (Dehydration) Section

In each of the three sections, convective heating is applied through a system of nozzles (Figure 3), enabling deep and thorough dehydration of the product (1). The



combination of pressurized nozzles (2) and vacuum nozzles (3) (Figure 4) ensures efficient airflow distribution, allowing for uniform drying of the product sheet.

Additionally, infrared heating elements (4) not only finalize the drying process but also enhance the flavor profile, giving the product characteristics similar to baked goods. The heating elements (5), controlled via a PID regulation system, maintain a consistent temperature on the steel conveyor belt, ensuring process stability.

This hybrid approach, combining convective and radiative heating, enables the production of high-quality flakes that stand out from those made using traditional drum dryers.

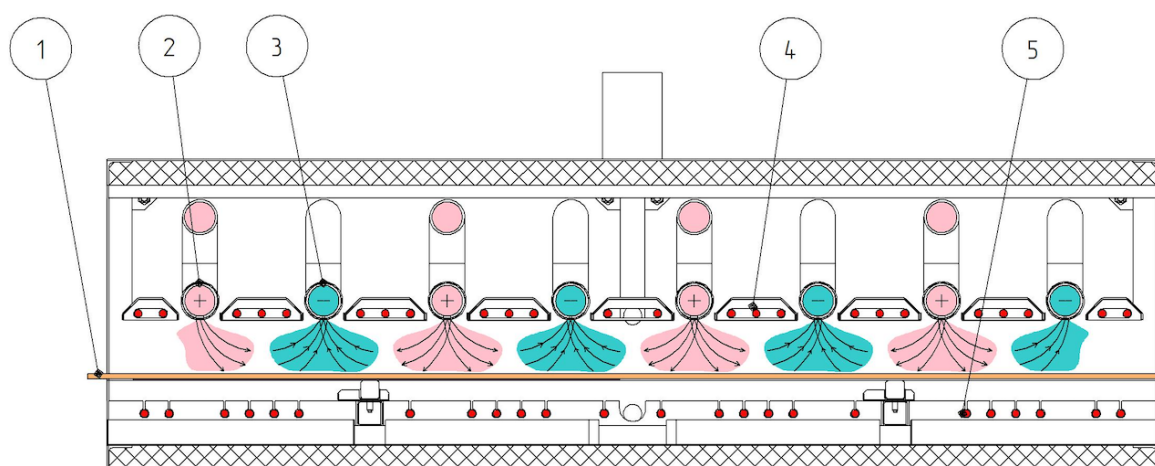


Figure 4 – Convection System of the Dehydrator.

Thus, the developed tunnel dehydrator design not only ensures efficient moisture removal but also enhances the sensory properties of the final product, making it more competitive in the confectionery market.

Three Heating Zones with Temperature and Airflow Regulation

The tunnel dehydrator consists of three independently controlled heating zones, each equipped with its own temperature and airflow regulation system. This allows for a gradual reduction in moisture content, preventing overheating or excessive drying.

- First zone – Initial dehydration stage. The temperature is kept at a moderate level to prevent sudden moisture evaporation and avoid product deformation.
- Second zone – Main drying stage. The optimal evaporation temperature is applied, allowing for the removal of the majority of moisture.



- Third zone – Final drying stage. This phase stabilizes the texture and preserves the product's sensory characteristics.

By adjusting temperature and airflow, the drying process can be tailored to different raw materials, including cereal flakes, fruits, vegetables, and protein-based ingredients.

Airflow Control in the Convection System

Achieving uniform drying is a critical factor in dehydration efficiency. Uneven moisture distribution can negatively affect texture, taste, and shelf life.

To evaluate the consistency of moisture removal, the coefficient of moisture variation (1) is used. This metric quantifies how evenly residual moisture is distributed across the product's surface and internal structure.

Formula for the coefficient of moisture variation:

$$CV = \frac{\sigma}{\bar{M}} \times 100\% \quad (1)$$

where:

CV – humidity variation coefficient (%),

σ - standard deviation of humidity (%),

\bar{M} - average moisture content of the product (%).

Calculation Method:

1. Moisture content is measured at several control points, with readings taken from five locations across both the surface and internal volume of the product.
2. The average moisture content is then calculated (2):

$$\bar{M} = \frac{M_1 + M_2 + \dots + M_n}{n} \quad (2)$$

where M_1, M_2, \dots, M_n – humidity at each point (%),

n – number of measurements.

3. The standard deviation is calculated using formula (3):

$$\sigma = \sqrt{\frac{\sum (M_i - \bar{M})^2}{n - 1}} \quad (3)$$



where M_i - the humidity at a specific point.

4. Calculate CV – the smaller the value, the more uniform the drying.

Measurement and calculation results:

1. After drying, residual moisture was measured at 5 points of the product:

$$M_1 = 6.0\%, \quad M_2 = 5.8\%, \quad M_3 = 6.2\%, \quad M_4 = 5.7\%, \quad M_5 = 6.1\%$$

2. Calculation of average humidity:

$$\bar{M} = \frac{6.0 + 5.8 + 6.2 + 5.7 + 6.1}{5} = 5.96\%$$

3. Calculating the standard deviation:

$$\sigma = \sqrt{\frac{(6.0 - 5.96)^2 + (5.8 - 5.96)^2 + (6.2 - 5.96)^2 + (5.7 - 5.96)^2 + (6.1 - 5.96)^2}{5 - 1}}$$

$$\sigma = \sqrt{\frac{(0.04)^2 + (-0.16)^2 + (0.24)^2 + (-0.26)^2 + (0.14)^2}{4}}$$

$$\sigma = \sqrt{\frac{0.0016 + 0.0256 + 0.0576 + 0.0676 + 0.0196}{4}} = \sqrt{0.042} \approx 0.205$$

4. Calculation of the coefficient of variation:

$$CV = \frac{0.205}{5.96} \times 100\% = 3.44\%$$

Conclusion:

The obtained value of the coefficient of variation $CV=3.44\%$ indicates a high uniformity of drying of the product in the tunnel dehydrator. Since this indicator is less than 5%, it can be concluded that the humidity is distributed evenly over the entire area of the product, which ensures stable quality of the final product.

Such results indicate the effectiveness of the air flow distribution system and zonal temperature control, which allows avoiding local overdrying or insufficient moisture removal.

Thus, the technological parameters of the tunnel dehydrator are optimally configured, and the system ensures a stable level of product quality without significant fluctuations in the residual moisture content.



Combination of Convective Heating and Infrared Elements

To achieve maximum drying efficiency, the system integrates two heating methods—convective and infrared heating—each playing a distinct role in the dehydration process:

- Convective heating ensures even heat distribution across the entire product surface. Hot air is directed through specialized nozzles, promoting rapid moisture evaporation without overheating the product.
- Infrared heating elements are applied during the final stage of dehydration, allowing for controlled evaporation of residual moisture while enhancing product texture. Infrared radiation creates a light baking effect, which improves flavor characteristics in the final product.

This hybrid drying approach optimizes the dehydration process, reduces energy consumption, and ensures a high-quality final product, aligning with modern food industry standards.

3.2. Technological Drying Process

The developed drying process in the tunnel dehydrator consists of several sequential stages, designed to achieve optimal moisture removal while preserving the structure and sensory properties of the final product.

Feeding the Ground Mixture into the Applicator

At the initial stage, the raw material is finely ground to a uniform consistency, allowing for even distribution across the drying surface. The grinding process is carefully controlled based on the physicochemical properties of the raw material, as particle size directly affects moisture evaporation rate and final texture.

The ground mixture is then fed into a specialized applicator, which ensures precise dosing and uniform distribution before dehydration begins. Automated feed control maintains a consistent product flow, preventing uneven layers and ensuring homogeneous drying.

Once inside the applicator, the mixture is spread onto the steel conveyor belt in a thin, even layer. This step is critical, as layer thickness directly influences dehydration uniformity. To prevent localized accumulation, the layer thickness adjustment



mechanism allows the process to be fine-tuned for different raw materials. This ensures gradual moisture evaporation, avoiding sudden temperature spikes that could lead to the formation of undesirable surface crusts.

Three-Stage Drying Process

The tunnel dehydrator operates on a three-stage drying system, designed to maximize product quality retention:

- Stage 1 – Gentle Preheating. The temperature is maintained at a moderate level to ensure gradual surface moisture evaporation, preventing overheating or deformation.
- Stage 2 – Primary Dehydration. In this zone, the optimal drying temperature is applied, ensuring active internal moisture removal. Heated air is evenly distributed, promoting fast yet controlled drying.
- Stage 3 – Stabilization. Here, the temperature is gradually lowered, allowing for final moisture removal and structural stabilization of the product.

This controlled drying approach prevents abrupt structural changes, which is particularly crucial for maintaining texture and flavor integrity.

Cooling and Final Processing

After passing through the heating zones, the dried product undergoes controlled cooling, ensuring stability of its physical properties. Gradual temperature reduction prevents condensation formation, which could otherwise compromise the final product quality.

The dried material is then processed into the desired particle size, depending on technological requirements. A precisely controlled grinding process ensures a uniform granulated product, making it easier for packaging and further application.

The proposed drying technology guarantees consistent product quality, reduces energy consumption, and preserves the natural characteristics of raw materials, making it a highly efficient solution for the modern food industry.

3.3. Methods for Evaluating Dehydrator Efficiency

To assess the performance of the tunnel dehydrator, a comprehensive evaluation methodology was developed. This approach allows for an objective measurement of



product quality, process optimization, and an assessment of energy efficiency. The key evaluation parameters include moisture content analysis, energy consumption studies, and sensory evaluation of the dried product.

Moisture Content Analysis

Monitoring moisture levels is a critical factor in dehydration efficiency, as it directly affects shelf life, texture, and flavor.

During the study, step-by-step moisture measurements were taken after each drying zone, allowing for the identification of optimal temperature settings and conveyor speed adjustments. The final moisture content was controlled according to technological requirements, ensuring consistent product quality without over-drying or excessive residual moisture.

For precise monitoring, gravimetric methods and rapid moisture analysis were used, enabling quick and accurate measurements in both laboratory and production environments. Optimizing this parameter resulted in improved texture stability and better product preservation during storage.

Energy Consumption Studies

Energy efficiency is a key factor in determining the economic viability of the tunnel dehydrator and its impact on production costs. The study analyzed electricity consumption at different drying stages and evaluated the efficiency of heat utilization.

Findings revealed that the combination of convective and infrared heating significantly reduces overall energy consumption. Infrared heating elements enable more efficient heat transfer, while convective airflow ensures even distribution of thermal energy across the drying surface.

Additionally, the use of zonal heating minimized unnecessary energy losses, as less heat was required in the initial and final drying stages, compared to the central zone of the dehydrator.

Sensory Evaluation (Texture, Crispness, Flavor Characteristics)

The quality of the final product was assessed through sensory analysis, focusing on texture, crispness, and flavor.

The study confirmed that a gradual temperature profile and controlled dehydration



process helped retain the product's natural flavor, preventing undesirable caramelization or structural degradation. Uniform moisture removal resulted in a consistent texture, ensuring pleasant crispness and high product quality.

The application of infrared heating in the final drying stage contributed to a light, desirable crispiness, making it particularly suitable for confectionery flakes and snack products. Moreover, a controlled cooling phase after dehydration prevented moisture reabsorption, further enhancing flavor stability.

Conclusion

The study results confirmed the efficiency of the developed drying process, enabling the optimization of dehydrator parameters to achieve consistent product quality with minimal energy consumption.

4. Results and Discussion

4.1. Comparison of the Tunnel Dehydrator and Drum Dryers

A detailed comparative study was conducted to evaluate the efficiency of tunnel dehydrators against traditional drum dryers. The findings indicate that tunnel dehydration provides a more stable drying process, ensures even heat distribution, reduces energy consumption, and enhances final product quality.

Advantages of a Continuous Drying Process

One of the key advantages of the tunnel dehydrator is its continuous operation, which helps maintain consistent product quality. In contrast, drum dryers operate in cycles, requiring periodic loading and unloading, which can lead to uneven drying and reduced production efficiency.

Unlike drum dryers, which rely on batch processing, the tunnel dehydrator functions in a fully automated mode, where the product moves smoothly along a conveyor belt through multiple drying zones with precisely controlled temperatures. This design boosts productivity, reduces manual labor, and minimizes production losses.

Superior Temperature and Airflow Control

The study revealed that the tunnel dehydrator offers precise temperature and airflow regulation within each drying zone, resulting in uniform moisture removal.



In drum dryers, temperature control is limited, as the product experiences brief but intense heat exposure during contact with the hot drum surface. This can cause localized overheating or incomplete drying, affecting the overall quality. In contrast, tunnel dehydration ensures even heat distribution through convective airflow, while gradual temperature reduction across different zones prevents rapid moisture evaporation, preserving the product's structure.

Additionally, the adjustable conveyor speed in tunnel dehydrators allows for process customization based on different raw materials—a level of flexibility not possible in drum dryers, where drying time remains fixed for all products.

Lower Energy Consumption and Improved Product Quality

Experimental data confirmed that tunnel dehydrators consume less energy than drum dryers, thanks to stage-wise heating and optimized thermal efficiency.

Drum dryers require high energy input to maintain elevated drum temperatures, leading to significant heat loss and higher operating costs. In contrast, tunnel dehydrators integrate convective heating with infrared elements (TEHs), maximizing energy efficiency and minimizing overall costs.

Enhanced Final Product Quality

The research also demonstrated that tunnel dehydration results in a more evenly dried product with superior texture, flavor retention, and structural stability.

Drum drying, on the other hand, often causes surface over-drying while leaving the inner layers excessively moist, negatively affecting crispness and uniformity. The gradual, controlled drying process in tunnel dehydrators prevents such inconsistencies, ensuring optimal product characteristics.

Conclusion

The study findings confirm that the tunnel dehydrator is a more technologically advanced and efficient solution compared to drum dryers. It delivers better product quality, lower energy consumption, and a more stable drying process, making it a highly effective choice for modern food production.

4.2. Efficiency of the Tunnel Dehydrator for Different Raw Materials

The developed tunnel dehydrator was tested on a variety of raw materials,



including grains, legumes, vegetables, and fruits. The results demonstrated that this innovative drying technology ensures even moisture removal, structural preservation, and improved sensory properties compared to traditional drying methods.

Grains and Legumes

Processing cereal flakes and legumes in the tunnel dehydrator proved highly effective in moisture control and texture stabilization. The gradual heating across multiple zones prevented sudden moisture loss, allowing for better structural integrity of the flakes.

A critical advantage was preventing excessive expansion or deformation of grains, a common issue in drum drying, where sharp temperature fluctuations cause uneven drying. Additionally, regulated convective drying optimized the natural caramelization of sugars in cereals, enhancing aroma and flavor without requiring additional sweeteners.

For legumes, the tunnel dehydrator maintained natural texture and minimized shell cracking, which is crucial for products that undergo further processing, such as powdering or granulation.

Vegetables

The dehydration of vegetables using the tunnel dehydrator preserved color, aroma, and nutritional content better than traditional drying techniques. Unlike conventional methods, which often result in significant shrinkage, tunnel dehydration effectively removed moisture while maintaining structural integrity.

The controlled temperature reduction in the final drying stage helped vegetables retain their natural elasticity, preventing excessive brittleness—a common issue with hot air or drum drying.

Particular attention was given to high-sugar vegetables such as carrots, pumpkins, and beets, which are prone to caramelization and darkening under excessive heat. The study confirmed that the tunnel dehydrator's precise temperature control effectively prevents these undesirable effects, preserving the vibrant natural colors of the vegetables.



Impact on Texture and Sensory Qualities

Comparative testing confirmed that tunnel dehydration delivers superior texture and flavor, thanks to consistent moisture removal without abrupt temperature changes. Products dried with this technology exhibited:

- Uniform crispness without excessive brittleness or internal moisture retention.
- More pronounced natural flavors, as overheating and undesirable chemical alterations were avoided.
- Preserved natural color, which is especially important for fruits and vegetables, as it serves as a key quality indicator for consumers.

The study confirmed that the tunnel dehydrator is a versatile solution for processing a wide range of raw materials. It optimizes the drying process, minimizes nutrient loss, and preserves high organoleptic quality, making it an indispensable technology for the modern food industry

4.3. Economic Feasibility Analysis

Assessing the economic efficiency of tunnel dehydrator implementation is crucial for manufacturers, as it directly impacts profitability, cost optimization, and long-term benefits. This analysis examines initial investment costs, operational expenses, and strategic advantages for the confectionery industry.

Initial Investment Costs

The adoption of a tunnel dehydrator requires significant capital investment, as the system includes a conveyor mechanism, multi-zone heating module, control system, and automation components. However, comparative analysis with alternative drying methods indicates that longer equipment lifespan and reduced operational costs make this a cost-effective long-term solution.

Installation costs cover facility preparation, equipment setup, and calibration of temperature and airflow control systems. However, the automation of the drying process significantly reduces labor costs, allowing businesses to recoup initial investments more quickly.

Operational and Maintenance Costs

A cost assessment confirmed that the tunnel dehydrator is significantly more



energy-efficient than drum dryers, thanks to optimized heat distribution and adjustable drying modes.

Key factors contributing to lower operating costs:

- Reduced energy consumption through a combination of convective and infrared heating, maximizing heat efficiency while minimizing waste.
- Lower maintenance requirements, as the tunnel dehydrator lacks high-wear mechanical components found in drum dryers.
- Easier cleaning and sanitation, thanks to accessible system design, reducing downtime and labor costs for maintenance.

Due to these advantages, operational expenses for tunnel dehydration are significantly lower than traditional methods, enabling manufacturers to cut production costs while maintaining high product quality.

Long-Term Benefits for Confectionery Manufacturers

The strategic advantages of tunnel dehydrator implementation extend beyond cost savings, offering significant long-term gains for manufacturers:

- Increased production efficiency. The continuous drying process eliminates downtime, allowing for higher production capacity—a crucial advantage in high-demand markets.
- Lower production costs. Energy efficiency and reduced maintenance expenses translate into a more cost-effective operation.
- Enhanced product quality. Superior moisture control and texture preservation improve final product appeal, boosting market competitiveness.
- Expanded product range. The flexibility of tunnel dehydration enables manufacturers to produce a wider variety of confectionery goods, including cereal flakes, fruit snacks, protein-based treats, and functional foods.

The economic analysis confirms that the tunnel dehydrator is a highly effective long-term investment (Table 1). It optimizes production costs, improves product quality, and enhances market competitiveness, making it an ideal solution for modern confectionery manufacturers.



Table 1 – Comparative Analysis of the Economic Feasibility of a Tunnel Dehydrator vs. a Drum Dryer

Parameter	Tunnel Dehydrator	Drum Dryer
Initial investment costs	\$80,000 – \$120,000	\$150,000 – \$250,000
Productivity	500 – 1200 kg/h	300 – 800 kg/h
Energy consumption	80 – 120 kW/h	180 – 250 kWh
Electricity costs (at average load)	4,000 – \$6,000/month (\$0.1/kW)	9,000 – \$12,500/month (\$0.1/kW)
Temperature control	Precise ($\pm 2^{\circ}\text{C}$), zone control	Less accurate ($\pm 5^{\circ}\text{C}$), depends on drum
Flexibility in raw material selection	High (grains, legumes, fruits, vegetables)	Limited (better for starchy blends)
Maintenance costs	1,500 – \$3,000/year	6,000 – \$10,000/year
Average equipment life	15 – 20 years	8 – 12 years
Product losses due to uneven drying	1 – 3%	5 – 10%
Return on investment	2.5 – 4 years	5 – 7 years
Long-term benefits	Low operating costs, stable quality	High energy and maintenance costs

5. Conclusions and Future Perspectives

5.1. Key Findings of the Study

The conducted research confirmed the efficiency of the tunnel dehydrator as an innovative solution for food drying applications. The analysis of technological parameters, economic feasibility, and final product quality led to the following key conclusions:

- The tunnel dehydrator ensures uniform drying, enhancing product quality. The multi-zone heating system and controlled airflow distribution prevent localized overheating, ensuring consistent dehydration across the entire product surface. This has a positive impact on texture, flavor, and sensory properties, particularly for grains, fruits, and vegetables.
- Reduced energy consumption and maintenance costs compared to traditional methods. By combining convective and infrared heating, the tunnel dehydrator optimizes heat distribution, significantly reducing electricity costs. Additionally,



the absence of high-wear mechanical components and a simplified cleaning system make this a cost-effective alternative to drum dryers.

- High scalability and adaptability. The modular design of the tunnel dehydrator allows for easy adaptation to various raw materials and production scales, making it suitable for small, medium, and large enterprises. Production capacity can be expanded without major investments, ensuring flexibility and competitiveness in the market.

The study demonstrated that integrating a tunnel dehydrator into food production leads to significant improvements in product quality, reduced operational costs, and enhanced drying efficiency—all crucial factors for modern food industry advancements.

5.2. Practical Application of the Results

The study confirmed the efficiency of the tunnel dehydrator, opening up a wide range of possibilities for its implementation in various food industry sectors. With high productivity, energy efficiency, and adaptability to different raw materials, this technology can be successfully integrated into confectionery production and other related industries.

Implementation in the Confectionery Industry

The use of tunnel dehydration optimizes the drying process for cereal and fruit-based ingredients, making it particularly valuable for the production of confectionery flakes, granola, fruit snacks, sugar-free cookies, and bars. The controlled drying process helps retain the natural flavor, texture, and color of the product, significantly enhancing its quality.

Additionally, this technology supports the expansion of functional and health-oriented food products, aligning with the growing consumer demand for healthier alternatives.

Application in Other Food Sectors

Beyond the confectionery industry, the tunnel dehydrator can be effectively utilized in the production of:

- Dried fruit and vegetable products (e.g., dried fruits, vegetable chips, fruit puree



sheets).

- Protein-based and functional foods (e.g., plant-based protein blends, sports nutrition, alternative protein products).
- Dehydrated convenience foods (e.g., instant soup mixes, dried grains, and legumes).

The flexibility of this technology allows it to be adapted for a wide range of food products, ensuring high quality and nutritional retention, making the tunnel dehydrator a universal solution for modern food production.

5.3. Future Research Directions

The findings of this study confirmed the efficiency of the tunnel dehydrator for drying various raw materials. However, further advancements in the technology could lead to higher productivity, lower energy consumption, and improved nutrient retention.

- Optimizing temperature settings to preserve nutritional compounds
Despite controlled dehydration, the process can still affect the structure of proteins, vitamins, and antioxidants, particularly in fruits, vegetables, and protein-based products. Future research will focus on identifying optimal temperature profiles for different raw materials, minimizing the loss of biologically active compounds while maintaining drying efficiency.

Additionally, studies will explore hybrid dehydration techniques that can shorten drying time and reduce thermal impact, ensuring maximum nutrient retention.

- Integrating advanced drying technologies (ultrasound, electromagnetic drying) for improved efficiency
A promising area of research involves innovative drying techniques that can accelerate dehydration, lower energy consumption, and enhance product texture.

One potential approach is ultrasound-assisted drying, which facilitates moisture evaporation at a microscopic level without overheating the product. Another avenue is electromagnetic drying, which enables even heat distribution while preventing localized overheating zones.

Further research in these areas will contribute to refining the drying process,



improving final product quality, and expanding the industrial applications of the tunnel dehydrator across various food production sectors.

References:

1. Kovalenko I.S. Глікемічний індекс як мірило якості кондитерських виробів у XXI столітті // The Level of Development of Science and Technology in the XXI Century, 2024. – DOI: 10.30890/2709-2313.2024-32-00-022.
2. Kovalenko I.S. Development of the Machine and Apparatus Scheme for the Production of Healthy, Crispy and Sugar-Free Flakes for the Confectionery Industry // SWorld Journal, 2024. – DOI: 10.30888/2663-5712.2024-27-00-030.
3. Mujumdar A.S. (Ed.). Handbook of Industrial Drying (4th ed.) // CRC Press, 2014.
4. Fellows P.J. Food Processing Technology: Principles and Practice (3rd ed.) // Woodhead Publishing, 2009.
5. Ratti C. Hot air and freeze-drying of high-value foods: a review // Journal of Food Engineering, 2001. – DOI: 10.1016/S0260-8774(00)00228-4.
6. Barbosa-Cánovas G.V., Ortega-Rivas E., Juliano P. Food Powders: Physical Properties, Processing, and Functionality // Springer, 2005.
7. Mujumdar A.S. (Ed.). Handbook of Industrial Drying (4th ed.) // CRC Press, 2014.
8. Fellows P.J. Food Processing Technology: Principles and Practice (3rd ed.) // Woodhead Publishing, 2009.
9. Ratti C. Hot air and freeze-drying of high-value foods: a review // Journal of Food Engineering, 2001. – DOI: 10.1016/S0260-8774(00)00228-4.
10. Zhang M., Tang J., Mujumdar A.S. Recent developments in novel drying technologies for foods // Drying Technology, 2009. – DOI: 10.1080/07373930802467593.
11. Chen X.D., Ozilgen M. Drying of food materials: principles, process modeling, and applications // Springer, 2017.
12. Slavin J.L. Dietary fiber and body weight // Nutrition, 2005. – DOI:



10.1016/j.nut.2004.08.018.

13. Goñi I., Garcia-Alonso A., Saura-Calixto F. A starch hydrolysis index to predict glycemic response in humans // Journal of Agricultural and Food Chemistry, 1997. – DOI: 10.1021/jf960678i.

14. Singh J., Dartois A., Kaur L. Starch digestibility in food matrix: a review // Trends in Food Science & Technology, 2010. – DOI: 10.1016/j.tifs.2010.02.002.

15. Brennan C.S. Dietary fibre, starch, and protein interactions: structural changes and nutritional properties // Food Chemistry, 2005. – DOI: 10.1016/j.foodchem.2005.04.028.

Анотація. Тунельний дегідратор є сучасним енергоефективним рішенням для сушіння харчових продуктів, зокрема для виробництва пластівців із низьким глікемічним індексом. Це має важливе значення у боротьбі з цукровою епідемією та ожирінням, адже дозволяє створювати продукти, що стабілізують рівень глюкози в крові. У статті проведено аналіз конструктивних особливостей дегідратора, визначено його переваги порівняно з традиційними барабанними сушарками, розраховано рівномірність висушування та економічну ефективність. Використання зонального нагрівання та контрольованої циркуляції повітря забезпечує рівномірне видалення вологи, збереження структури вуглеводів і мінімізацію втрат поживних речовин. Результати дослідження дозволяють оптимізувати параметри роботи дегідратора та розробити рекомендації для його впровадження у харчову промисловість.

Ключові слова: тунельний дегідратор, дегідrataція, сушіння харчових продуктів, пластівці з низьким глікемічним індексом, енергоефективність, рівномірність висушування, контрольована циркуляція повітря, збереження поживних речовин, харчова промисловість, технологія сушіння.

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