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ANALYSIS OF PRESSURE EFFECTS ON THE EVAPORATION OF TOMATO PULP.

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Abstract. This paper presents the results of an investigation into the dependence of the evaporation rate of tomato pulp on system pressure. Experimental findings demonstrate that intensifying heat and mass transfer processes under elevated pressure significantly reduces the duration of moisture removal. The results obtained may be used to enhance the efficiency of industrial processing lines in food production.

Keywords: tomato pulp, evaporation rate, system pressure, heat transfer, mass transfer, moisture removal, process intensification, food processing technology, industrial drying, energy efficiency.

Аннотация. В статье представлены результаты исследования зависимости скорости выпаривания томатной пульпы от давления в системе. Экспериментально доказано, что интенсификация процессов тепло- и массообмена при повышенном давлении существенно сокращает время влагоудаления. Предложенные данные позволяют повысить эффективность технологических линий в производстве.

Ключевые слова: томатная пульпа, скорость испарения, давление системы, теплообмен, массообмен, удаление влаги, интенсификация процессов, пищевая технология, промышленная сушка, энергетическая эффективность.

Annotatsiya. Ushbu maqolada pomidor pulpasining bug‘lanish tezligining tizim bosimiga bog‘liqligi bo‘yicha olib borilgan tadqiqot natijalari keltirilgan. Tajriba natijalari shuni ko‘rsatadiki, yuqori bosim sharoitida issiqlik va massa almashinuvi jarayonlarini jadallashtirish namlikni chiqarish vaqtini sezilarli darajada qisqartiradi. Olingan natijalar oziq-ovqat ishlab chiqarishdagi texnologik liniyalarning samaradorligini oshirishga xizmat qilishi mumkin.

Kalit so‘zlar: pomidor pulpasi, bug‘lanish tezligi, tizim bosimi, issiqlik almashinuvi, massa almashinuvi, namlikni yo‘qotish, jarayonlarni jadallashtirish, oziq-ovqat texnologiyasi, sanoat quritish jarayoni, energiya samaradorligi.

INTRODUCTION.

Tomato pulp is an important raw material component in the production of food products such as tomato pastes, sauces, and juices. The quality of the final product is largely determined by the physicochemical properties of the pulp, among which viscosity, structure, final product color, and overall quality are of particular importance.Traditional methods of concentrating tomato pulp are based on thermal evaporation; however, these processes may lead to a deterioration of organoleptic properties, loss of biologically active compounds, and changes in the structural characteristics of the product. Evaporation represents one of the most important unit operations in tomato pulp processing, primarily used to increase soluble solids concentration while maintaining desirable physicochemical, sensory, and nutritional properties of the final product. The efficiency of this process depends on several operational parameters, among which pressure plays a critical role. While temperature is commonly regarded as the principal factor influencing evaporation, pressure directly affects vapor–liquid equilibrium, boiling point elevation, heat transfer characteristics, and mass transfer efficiency, thereby significantly determining the overall performance of the concentration process.Under conventional industrial practice, tomato pulp concentration is generally conducted under reduced pressure to lower the boiling point of water and minimize thermal degradation. Vacuum evaporation allows water removal at relatively low temperatures, which helps preserve color, aroma, viscosity, and heat-sensitive bioactive compounds. However, operation under elevated pressure conditions, such as 6 atm, produces substantially different thermodynamic behavior. According to the Clausius–Clapeyron relation, increasing system pressure raises the saturation temperature of water to approximately 160°C, requiring the tomato pulp to reach significantly higher temperatures before phase transition can occur.

Elevated-pressure evaporation offers several operational advantages. Higher processing temperatures increase the thermal gradient between the heating medium and the product, resulting in improved heat transfer coefficients and faster energy transfer rates. Additionally, operation at elevated pressure reduces foam formation and provides simultaneous microbial inactivation, contributing to improved process stability and product safety. Nevertheless, these advantages are accompanied by significant drawbacks related to product quality deterioration. High-temperature exposure accelerates non-enzymatic browning reactions, particularly the Maillard reaction, and promotes degradation of thermolabile compounds such as lycopene, which is responsible for the characteristic red color and antioxidant properties of tomato products. Furthermore, prolonged thermal

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treatment may induce pectin breakdown, viscosity reduction, and undesirable flavor alterations.

To overcome these limitations, advanced concentration technologies frequently incorporate the pressure drop method, also known as flash evaporation. This method involves preheating tomato pulp under elevated pressure followed by rapid depressurization into a low-pressure chamber. The sudden pressure reduction causes immediate partial vaporization of water, resulting in rapid evaporative cooling and efficient moisture removal. This approach enables partial utilization of stored thermal energy while reducing residence time at elevated temperatures, thereby minimizing thermal damage to the product.

Therefore, in recent years, alternative processing methods aimed at preserving raw material quality have been actively investigated.One promising approach is the evaporation of tomato pulp under pressure differential conditions. This method intensifies moisture removal by lowering the boiling point of the liquid under reduced pressure and also affects the microstructure of the pulp, promoting the release of cellular components, including pectic substances. The application of a pressure differential can significantly influence evaporation time and the rheological properties of the tomato system, including its viscosity and storage stability. In this regard, a comprehensive study is required to evaluate the effect of this processing method on the structural and mechanical characteristics of tomato pulp.The aim of this study is to investigate the process of tomato pulp evaporation under pressure differential conditions, to analyze the dependence of evaporation time on pressure level, and to identify the patterns that determine the efficiency of the concentration process.

Experimental data demonstrate a consistent trend of decreasing evaporation time with increasing pressure. Tomato pulp consists of plant cells filled with juice and surrounded by rigid cell walls composed of cellulose and pectin. Within the cell walls of tomatoes, pectin acts as a natural thickening agent.

Mechanism: a sudden pressure drop releases bound pectin from disrupted cells into the bulk system. As a result, pectin begins to actively bind water. The pressure differential also reduces the particle size of the solid phase (pulp fraction). Before treatment, particle sizes typically range from 500–1000 microns, whereas after treatment they decrease to less than 100 microns. Due to the pressure differential, a more uniform structure is formed, in which fine particles are evenly distributed and stabilized by a pectin network.

Pressure differential during evaporation improves texture by reducing the size of solid pulp particles and forming a stable, homogeneous structure. Elevated pressure conditions promote structural stabilization of the pulp and enable fine disintegration of fibrous components, allowing them to remain in suspension.

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Homogenization prevents phase separation of the juice, as smaller particles remain suspended for a longer time and do not settle as sediment.

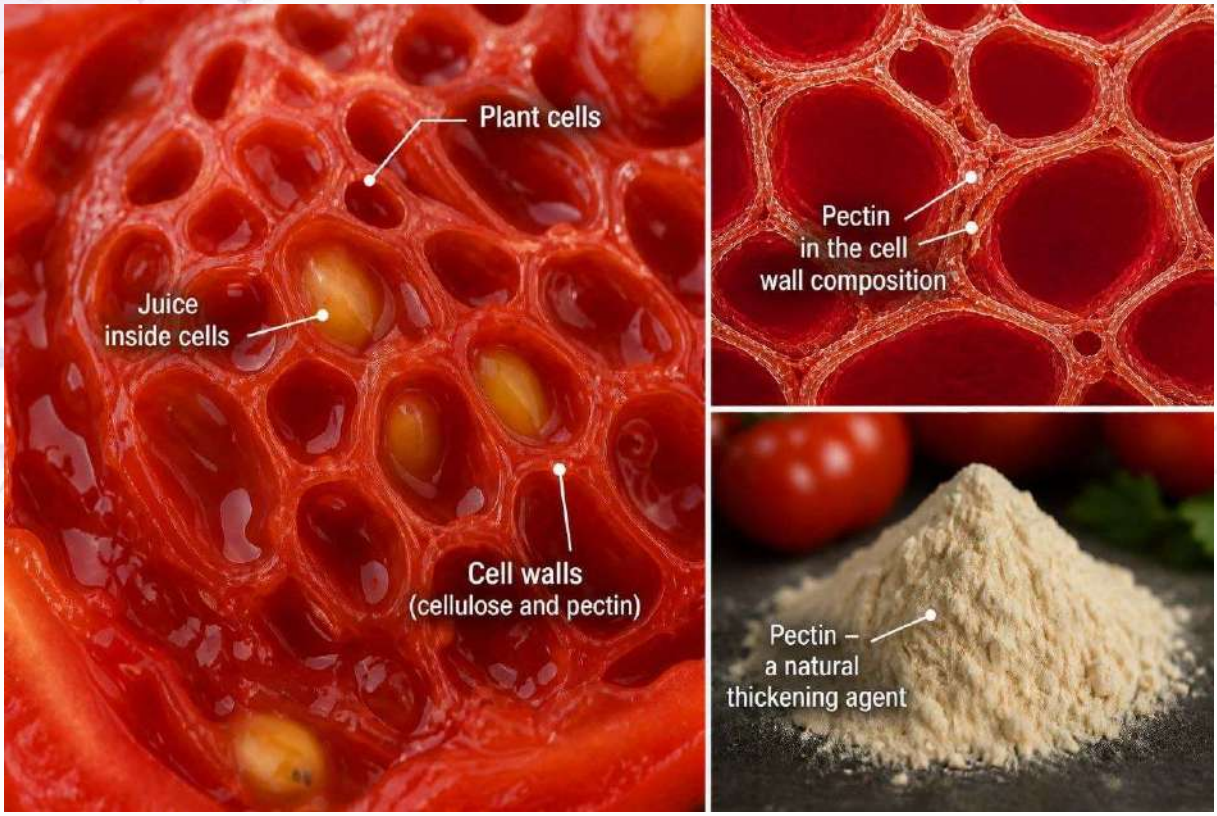


Figure 1. Structure of the product after pressure differential treatment

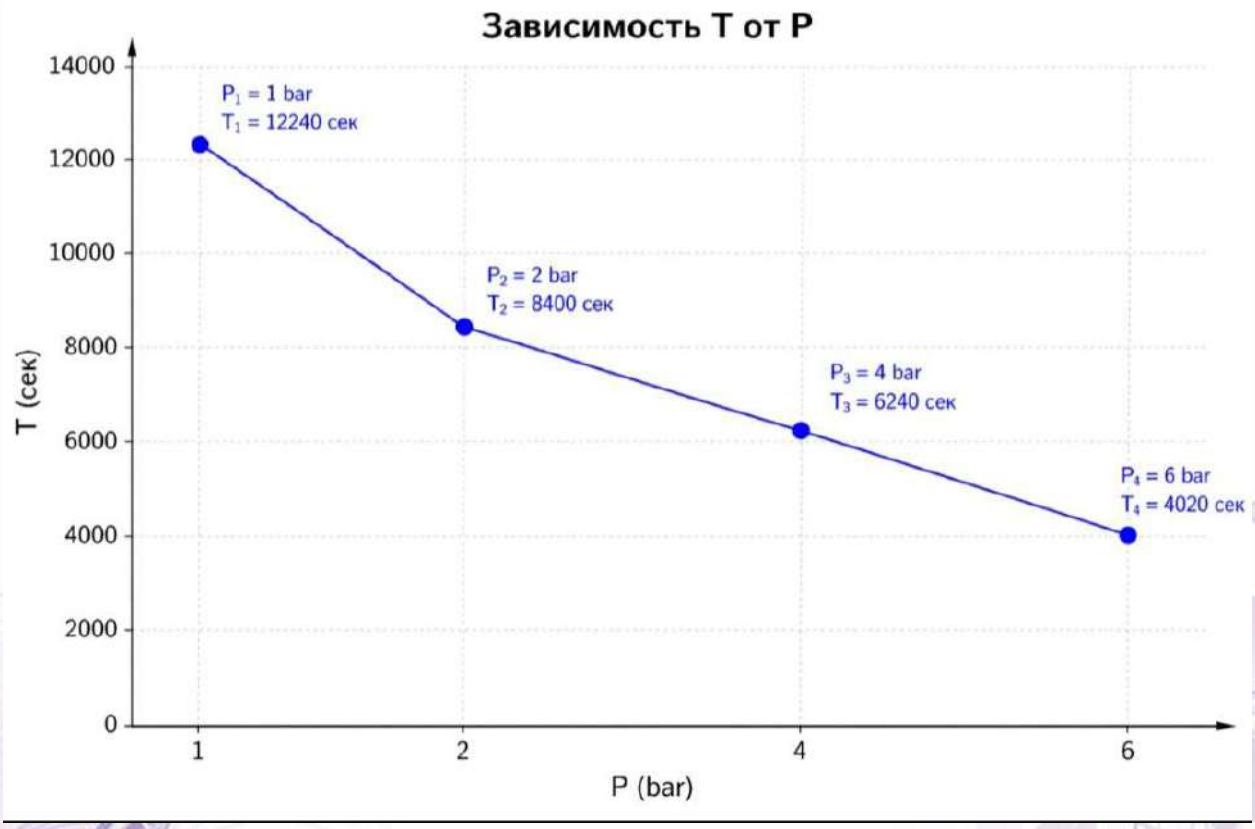


Figure 2. Analysis of the dependence of tomato pulp evaporation time on pressure

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The graph shows the dependence of tomato pulp evaporation time on the pressure in the system. The x-axis represents pressure (bar), while the y-axis represents evaporation time (seconds).The experimental data demonstrate a consistent decrease in process duration with increasing pressure. At atmospheric pressure (1 bar), the evaporation time is 12,240 s. Increasing the pressure to 2 bar reduces the time to 8,400 s. Further increases to 4 bar and 6 bar lead to evaporation times of 6,240 s and 4,020 s, respectively. The observed relationship is inverse and nonlinear in nature, indicating an intensification of heat and mass transfer processes at elevated pressures. An increase in pressure raises the boiling point and the heat transfer coefficient, which accelerates moisture removal from the pulp and, consequently, shortens the concentration time.

In comparison with vacuum-based evaporation systems, operation at elevated pressure (e.g., 6 atm) provides a more stable boiling regime. The higher system pressure reduces the likelihood of abrupt pressure fluctuations, thereby minimizing the risk of sudden boiling disturbances or process instabilities. As a result, vapor formation tends to occur in a more controlled and uniform manner. This contributes to improved operational consistency, particularly in continuous processing systems where maintaining steady-state conditions is essential. Furthermore, the reduced sensitivity to pressure variations simplifies process control and enhances the reliability of industrial equipment.

Evaporation under elevated pressure conditions offers several technical and operational advantages:

Enhanced heat transfer rates due to increased temperature gradients between the heating medium and the product.

Reduced foaming tendency, leading to improved process stability and simplified equipment requirements.

Inherent microbial inactivation and enzyme deactivation as a result of high-temperature conditions.

Partial retention of certain volatile compounds during the initial stages of processing, prior to thermal degradation.

Potential for more compact equipment design due to higher heat transfer efficiency.

Improved stability of operation with reduced pressure fluctuations.

The obtained results are of significant practical importance for optimizing evaporation regimes. Increasing pressure can be considered an effective method for intensifying the technological process, allowing a reduction in energy consumption over time and an improvement in equipment productivity. The experimental results confirmed that increasing system pressure enhances heat and mass transfer processes, thereby significantly reducing the time required for

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moisture removal. These findings indicate that pressure intensification can be effectively utilized to improve the efficiency of industrial processing lines in food production technologies.

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