ABSTRACT
of the dissertation work by Satybaldy Symbat Perdebaykyzy
on the topic: "Design and calculation of equipment for vacuum freeze-drying of mare's milk"
submitted for the degree of Doctor of Philosophy (PhD)
in the educational program 8D07110 – "Digital Engineering of Machines and Equipment"

Relevance of the Research Topic

Currently, the development of energy-efficient, automated, and environmentally safe technologies and equipment holds special significance in the food and mechanical engineering industries of the Republic of Kazakhstan. To obtain products of high biological value by processing mare's and camel's milk (saumal, koumiss, shubat), the use of low-temperature vacuum freeze-drying technology is considered effective.

Traditional convective drying methods do not ensure the preservation of the amino acid and vitamin composition of the product. Therefore, research aimed at the design and calculation of new energy-efficient and automated equipment that implements the process of vacuum freeze-drying is an urgent scientific and engineering task.

Purpose of the Research

To design and calculate an energy-efficient and high-performance vacuum freeze dryer of a new generation for drying mare's milk at low temperatures, to create its digital model, and to implement it under industrial conditions.

Research Idea

- To create a digital twin of the new technological equipment and optimize it based on the modeling of heat and mass transfer processes.
- Research Concepts
- Study of the dynamics of heat and mass transfer during vacuum sublimation;
- Strength analysis of the main units (sublimator, condenser, vacuum chamber, pneumatic system);
- Design of an automated process control system (APCS);
- Implementation of equipment modeling in Autodesk Inventor, APM WinMachine, COMSOL Multiphysics, and Ansys environments.

Research Objectives

- To analyze vacuum freeze-drying technologies and determine the main technical parameters;
- To develop a mathematical model of heat and mass transfer processes;
- To perform strength calculations and optimize the structural elements of the equipment;
- To determine the operating parameters of the condenser and vacuum chamber;
- To create a 3D model and design an automated control system;
- To manufacture an experimental prototype and conduct industrial testing;
- To evaluate the technical and economic efficiency of the equipment.
- Scientific Provisions Submitted for Defense
- A mathematical model describing the regularities of heat and mass transfer during vacuum sublimation of mare's milk has been developed.
- A new energy-efficient condenser design has been proposed, and its heat exchange surface and temperature regimes have been determined.
- Strength analysis of the vacuum chamber and heat-conducting elements has been carried out using APM WinMachine and Autodesk Inventor software.
- A digital model of the vacuum dryer has been created and tested under industrial conditions.

Scientific Novelty

- For the first time in Kazakhstan, a digital model of a vacuum freeze-drying unit for drying mare's and camel's milk has been developed.
- An improved mathematical algorithm for calculating the movement of the sublimation front has been proposed.
- The strength and thermal conductivity of the condenser and vacuum chamber have been modeled using the Finite Element Method (FEM).
- A new condenser design with a multistage cooling system has been developed.
- A control system enabling remote monitoring and automatic recording of process parameters has been created.

Practical Significance of the Work

- Based on the research results, an experimental prototype was manufactured and successfully tested in production conditions.
- The new equipment reduces energy consumption by up to 20%, improves product quality, and increases process stability.
- The equipment is recommended for use at domestic enterprises in the food, biotechnology, and pharmaceutical industries.

Methodology and Research Methods

- The research employs a set of analytical, experimental, and numerical methods:
- Modeling of heat and mass transfer processes in COMSOL, Maple, and Python environments;
- Strength calculations in APM WinMachine, Ansys, and Autodesk Inventor;
- Laboratory tests and microbiological analysis;
- Data processing using methods of mathematical statistics and regression analysis.

Applicant's Personal Contribution

- Developed the mathematical model and calculation algorithm;
- Designed the 3D model of the equipment and performed digital calculations;
- Organized industrial testing and analyzed the obtained data;
- Prepared scientific articles and a patent application.
- Processing of Research Results
- Experimental data were processed using Python, MATLAB, and Excel Engineering Toolkit. The accuracy of the model was confirmed with a deviation of ±5%. Correlation and regression analysis confirmed the reliability of the proposed model.

Approbation of Results

The research results were presented at international and national scientific and technical conferences and discussed at scientific seminars.

Publications

Based on the results of the doctoral dissertation, the following have been published:

- 2 articles in Scopus-indexed journals (CiteScore, Q1);
- 1 article in a journal recommended by the Committee for Quality Assurance in the Field of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan;
- 1 report at international conference;
- 1 patent of the Republic of Kazakhstan for a utility model.

Structure and Volume of the Work

The dissertation consists of an introduction, four chapters, a conclusion, a list of references, and appendices.

The total volume is 111 pages, including 32 figures, 7 tables, 62 sources, and 6 appendices.