Review advances of Automation and Computer Engineering Department in the field of canned food sterilization over the past decade

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Abstract. Time-consuming computing processes at various stages of modern scientific research are increasingly being automated in recent decades. The staff of Automation and Computer Engineering Department together with the Food Production Technology Department of Murmansk State Technical University have been solving the challenge of developing comprehensive automation of scientific research for food production technology for more than one decade. As a result, they have been achieved the great success in the field of food products sterilization from aquatic organisms. Most research in the canning field is aimed at increasing the economic process efficiency and maintaining the microbiological safety and organoleptic qualities of the finished product. In the article main advances of scientific research on the process of canned food sterilization are considered and analyzed. Also plans for future research work are outlined.

1. Introduction
Time-consuming computing processes at various stages of modern scientific research are increasingly being automated in recent decades. It became possible due to the intensive development of computer engineering power and mathematical, imitation and neuro-fuzzy modeling. Generally, comprehensive automation of scientific research combines laboratory equipment control, measuring and recording experimental data, collecting, storing and processing the obtained data. Despite this, the further realization of comprehensive automation of scientific research is rather difficult. The main problems for this are:

– development of hardware and software suitable for a specific scientific research area and capable of adapting and tuning under changing environmental conditions;
– tendency of automation to destroy the creative process as part of the scientific research.

The staff of the Automation and Computer Engineering (A&CE) Department together with the Food Production Technology (FPT) Department of Murmansk State Technical University (MSTU) have been solving the challenge of developing comprehensive automation of scientific research for food production technology for more than one decade. The greatest successes have been achieved in the field of food products sterilization from aquatic organisms.

Next, the main advances of scientific research at MSTU on the process of canned food sterilization are considered and analyzed.

2. Main advances in the field of canned food sterilization
2.1. Sterilizing equipment

Continuous sterilization process improvement is determined by the fact that this process is crucial for quality assessment of finished canned food products from aquatic organisms. Most research in the canning field is aimed at increasing the economic process efficiency while maintaining the microbiological safety and organoleptic qualities of the finished product. Since at the end of 2007 there were no inexpensive and effective domestic sterilization equipment on the market, A&CE and FPT departments of MSTU chose this variant.

Within a few years, the modern, energy-efficient and inexpensive sterilization unit AVK-30 was created on the basis of the medical sterilizing equipment VK-30. After conducting data obtaining studies on the operation of the installation several shortcomings, regarding energy efficiency, were identified. The main of them are the presence of significant heat losses through the medical sterilizing equipment walls and the necessary reduction of water volume heated at the initial stage. The installation into the sterilizing equipment of the thermal insulation and the special “economizer” made it possible to increase the energy efficiency of the AVK-30 sterilization unit (Figure 1, useful model patent No. 94418, Russian Federation). “Economizer” is the high-pressure vessel designed to accumulate the media used in the autoclave chamber during the cooling stage and it subsequent use during reheating [1].

Figure 1. Sterilization equipment AVK-30: 1 - compressor; 2 - air receiver; 3, 10, 14 - overpressure sensors; 4, 9, 27 - manometers; 5 - temperature sensor in the sterilization chamber; 6 – sterilization chamber cap; 7 - baskets with cans; 8 - autoclave outer jacket; 11 - air supply valve; 12 - sterilization chamber; 13 - temperature sensor in the steam generator; 15 - valve for supplying cooling water to the sterilization chamber; 16 – water-vapor chamber (steam generator); 17 - tubular electric heaters; 18 - valve for supplying water to the steam generator; 19 – valve for draining from the sterilization chamber; 20 - valve for draining from the sterilization chamber to the economizer; 21 - valve for draining from economizer; 22 - steam supply valve; 23 - valve for draining from the steam generator to the economizer; 24 - drain valve; 25 - temperature sensor in the economizer; 26 - economizer; 28 - valve for draining from economizer to steam generator; 29 - control system

2.2. Control system for the developed sterilization equipment
Further, the control system for the sterilization equipment AVK-30 on the basis of domestic company OWEN equipment for general industrial automation and its operation algorithm were developed at the A&CE department. Thus, complex MIST (Modeling, Identification, Sterilization), shown on the figure 2, was created and completely integrated into the sterilization equipment to carry out research and develop an optimal automatic control system (ACS) for the canned food sterilization from aquatic organisms in 2011. Since the control system is built on the basis of general industrial automation equipment available for majority of Russian enterprises, complex MIST can be used for any industrial autoclave after preliminary configuration. Practically, it means that the cost-effectively ACS development for a given autoclave is possible.

Figure 2. Complex MIST

In 2011, the search of the optimal regulator for the developed control system is begun. In the article "Method for optimal temperature control in an autoclave based on a regulator with prediction" researchers from the A&CE department conducted a study of the optimal-tuned proportional-integral regulator. Performed on the sterilization equipment AVK-30 experiments and numerical mathematical simulation of food products sterilization from aquatic organisms resulted in that the use of the “predicted” algorithm in the ACS operation saves up to 20% of the media compared to the traditional control method when the sterilization regime requirements are met [2].

2.3. “Modernized” canned food sterilization regime

As a part of the research work for improving the energy efficiency of food thermal processes, "modernized" sterilization regime of canned foods from hydrobionts, shown on figure 3, was proposed in 2011 (Invention No. RU2471387C1 "Preserves sterilisation process control method based on F-
effect”). This regime is based on the optimal sterilization formula with actual sterilizing effect (F-effect) calculation. The ACS of sterilization process in the sterilization equipment AVK-30 uses it as a controlled parameter. This makes it possible to achieve up to 30% power savings compared to the traditional sterilization regime and reduce the duration of sterilization equipment operation by 9% [3, 4]. One of the method disadvantages is the necessity of temperature sensor inside the canned food and F-effect calculation in real-time. Because of the implementation possibility of a new canned food sterilization regime, it was decided to change the name of the sterilization equipment to AVK-30M [5].

![Diagram](image)

**Figure 3.** Stages of “modernized” canned food sterilization regime: A – duration of heating to sterilization temperature $T_{CTK1}$; B – duration of sterilization at temperature $T_{CTK1}$; C – duration of transition from sterilization temperature $T_{CTK1}$ to temperature $T_{CTK2}$; D – duration of sterilization at temperature $T_{CTK2}$; E – duration of cooling stage; P – pressure in the autoclave sterilization chamber; L – normative sterilizing effect

### 2.4. Software complex

In 2011, the employees of A&CE department selected a research vector in the direction of developing a special software package for the canned food sterilization from aquatic organisms. Such complex allows obtaining adequate temperature models of the sterilization process and subsequent use of them in optimization of sterilization regime parameters according to the specified quality criteria or the F-effect of the finished product. By 2019, development of the software complex TPM & PRSC was completed.

The software complex for obtaining sterilization regime of canned food from hydrobionts at the preliminary selection stage consists of two programs: TPM and PRSC.

To start working with TPM software user need to open file with registered data from temperature loggers. Next, select the desired product temperature profile, type and order of product thermal model. Then user need to click «Model Identification» button and save selected product model and sterilization regime to files for PRSC software where further mathematical simulation is performed [6].

In 2011, the development of the PRSC software was started in the integrated programming environment (IDE) Lazarus in order to mathematically simulate the sterilization regime of canned food from hydrobionts. This program allowed to find optimal by normative sterilizing effect,
sterilization temperature and process stages duration parameters of the sterilization regime of canned food using adaptive simplex method [7]. At the first optimization step, a simplex is built according to pre-known coordinates. Next, obtained the worst result simplex point is selected. Then the coordinates of this point are mirrored relative to the opposite face of the simplex. The worst point is replaced by the resulting one and a new simplex, directed towards improving the optimization result, is obtained. At the obtained point the new experiment is carried out and the result is again compared with other simplex points. So, this is how the simplex moves over the response surface. The process is repeated until the optimum region is reached. It is the region where the translational motion of the simplex stops and the simplex rotates around one of the vertices (looping). Parameters of the final simplex in the optimum region are stored for next calculations. This ensures that initial parameters information of the optimization object is accumulated for next simplex method application.

Each process model calculation with new coefficients or parameters of sterilization regime is carried out using the classical numerical integration Runge-Kutta fourth-order method. This method makes it possible to calculate the product model or sterilization process with accuracy up to $10^{-5}$.

A detailed functions description of the software complex TPM & PRSC and an example of its use in solving the real problem are given in the article [6].

As a result of the research carried out using the software complex TPM & PRSC, the employees of A&CE department concluded that due to the simulation and optimization processes using computer technology [8], it is possible to significantly reduce the development of new product sterilization regimes and speed up the commissioning of new sterilizing energy efficient equipment. This equipment probably improves the final product quality and safety.

2.5. Economic method of sterilization regimes development

In 2015, the utilization of the software complex together with the sterilizing equipment AVK-30M made it possible to implement a cost-effective methodology for the canned food sterilization regimes development for an industrial autoclave. All studies during new regimes development for canned food sterilization were carried out using the industrial autoclave ASCAMAT-230 (Figure 4). This was because the application from fishing enterprises of the Murmansk region for the sterilization regimes development for this type of autoclaves was received in 2015.

![Industrial autoclave ASCAMAT-230](image)

**Figure 4.** Industrial autoclave ASCAMAT-230: 1 – autoclave body; 2 - basket; 3 - pressure sensor; 4 - temperature sensor; 5 - manometer; 6 - waste valve; 7 - cooling water supply valve; 8 - steam drain valve; 9 - tubular electric heaters; 10 - safety valve; 11 – cap protective manual valve-blocker.
Proposed by the research group of A&CE and FPT departments method essence is to quickly reconfigure operation algorithms of the ACS in the sterilizing equipment AVK-30M at any sterilization stage to simulate the industrial autoclave sterilization regime in accordance with the task. Use of AVK-30M resulted in the savings of electricity up to 85% and raw material consumption for one test autoclaving up to 90% [9].

The main complexity of this method's widespread implementation remains the presence of the autoclave correct temperature profile chosen for the canned food sterilization regime selection. It is happened due to the temperature field non-uniformity in the sterilization chambers of industrial autoclaves during heating and cooling stages.

2.6. Temperature field and mathematical model of industry autoclave

In 2017, employees of the A&CE and FPT departments conducted a study of the sterilization chamber temperature field for the industrial autoclave ASCAMAT-230. This autoclave was received from one of the enterprises of the Murmansk region in order to eliminate the above-mentioned main complexity of the economic method. The temperature field parameters were determined using a special procedure to study the heating medium temperature field of periodic equipment for canned food sterilization [10]. For this purpose, six temperature loggers Thermochron series DS1922 were located inside the autoclave sterilization chamber. The first one was placed in the place of standard thermometer installation. The second, third, fifth and sixth of them were respectively located at the center and periphery of the lower and upper portions of the autoclave sterilization chamber. The fourth one was placed in the center of the middle part of the autoclave sterilization chamber. Temperature measurement in tin cans with the product was carried out by temperature loggers Ellab TrackSense PRO. Loggers were installed in tin cans located at the top and bottom of the autoclave sterilization chamber. Correctness and accuracy of Thermochron and Ellab loggers' temperature values meet the requirements for technical means of temperature measurement during product thermal treatment in an autoclave [11].

Based on the obtained information, temperature versus time dependencies for the sterilization process of the autoclave characteristic points are built and the conclusion on the temperature field uniformity of the industrial autoclave ASCAMAT-230 is made. At the sterilization stage, the temperature field can be considered uniform (temperature difference is not more than 1°C in different regions of autoclave and tin cans with the product). At the cooling stage, it is not uniform due to the cooling water supply first to the bottom part of the autoclave. This is a constructive feature of the autoclave ASCAMAT-230 [10].

Some recommendations for the use of an industrial autoclave ASCAMAT-230 were made based on the study results:

− it is recommended to place tin cans with the product in the lower basket of the autoclave to sustain the set time-temperature regime at a cooling stage during the new sterilization regimes development;
− to place temperature loggers in the lower and top parts of the autoclave is the best way to maintain temperature on a preset value at the sterilization stage during creation of ACS for autoclave;
− F-effects’ difference in the top and lower baskets of the autoclave is not less than 10% during the canned food sterilization process.

By 2018, based on these recommendations the numerical mathematical model of the industrial autoclave ASCAMAT-230 was obtained and the variant to upgrade the existing ACS was proposed.

The mathematical description of the autoclave sterilization chamber is presented using the second-order transfer function, while the numerical mathematical model maximum deviation from the real temperature value did not exceed 2°C [12].

The obtained result can be used for the existing ACS modernization of autoclave ASCAMAT-230 with optimal regulator parameters. To do this is needed to make the following changes [13]:

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– replace the factory microprocessor controller with a domestic programmable controller to implement a control algorithm of almost any complexity, program sensor calibration and required parameters’ calculation;
– change manually operated valves to electromechanical to automate operations during the cooling stage;
– install a control unit for triacs and thyristors instead of contactors to improve control accuracy and reduce energy costs;
– provide the ability to connect the ACS to a computer for data recording, processing, and analysis.

2.7. Canned food sterilization process simulator
One of the most perspective advances of the A&CE department is the canned food sterilization process simulator in complex with ACS for the sterilization process (figure 5). ACS is based on the modern domestic equipment for automation by production association OWEN. ACS is located in the panel controller SPK-207 and is connected to the autoclave-simulator by means of I/O modules. Discrete signals of the top level, water, steam, air and of the cover opening come to the ACS. Then it generates signals for valves of the cooling water supply, air, steam and valves of waste and drain.

![Figure 5. Canned food sterilization process simulator with ACS](image)

The program model of an autoclave was implemented inside the canned food sterilization process simulator (certificate of software registration No. 2015663349, Russian Federation). It calculates the process parameters in real-time in accordance with the parameters of the nutrient media, the product and the environmental impact. The simulator allows modeling abnormal situations (failure of actuators) by disconnecting the valve from the ACS using special connectors on the simulator [14].

At present, the canned food sterilization process simulator is the training and laboratory stand for teaching students of the direction "Automation of technological processes and production" and serves to demonstrate approaches to the ACS design.

3. Conclusion
Authors of the article expect that the presence of patented developments related to hardware and software as well as a large number of developed and approved canned food sterilization regimes for
industrial autoclaves will contribute to the establishment of an automated research system for the food products sterilization from hydrobionts in near future.

Also, the improvement of software complex TPM&PRSC functionality will allow creating a computer-aided design system for sterilization regimes of canned food from hydrobionts at the regime selection preliminary stage. It will significantly shorten the development time for a new or correction an existing sterilization regime of canned food.

References
[1] Maslov A et al 2009 Vestnik of MSTU 12(2) 263-267
[2] Maslov A et al 2011 Vestnik of MSTU 14(3) 520-524
[3] Vlasov A et al 2012 Vestnik of MSTU 15(1) 49-53
[4] Vlasov A et al 2013 Vestnik of MSTU 16(3) 560-565
[5] Ereshchenko V et al 2015 Vestnik of MSTU 18(1) 110-116
[6] Stolyanov A et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 403 012016
[7] Selyakov I et al 2014 Vestnik of MSTU 17(1) 46-52
[8] Kuranova L et al 2016 Vestnik of MSTU 19(4) 861-868
[9] Vlasov A et al 2015 Vestnik of MSTU 18(4) 661-666
[10] Grokhovsky V et al 2017 Vestnik of MSTU 20 3 563-571
[11] Stolyanov A et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 302 012031
[12] Kaychenov A et al 2018 VESTNIK OF ASTRAKHAN STATE TECHNICAL UNIVERSITY. SERIES: MANAGEMENT, COMPUTER SCIENCE AND INFORMATICS 1 7-17
[13] Zhuk A, Kaychenov A 2017 The collection of materials of the youth forum "Young Arctic Science" (Murmansk, November 16–17, 2017) 18-21
[14] Kaychenov A et al 2020 KnE Life Sciences 437-449