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AUTOMATION OF ELECTRIC AUTOCLAVE CONTROL

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The article analyzes the use of an electric autoclave with the proposed system of automated control of the technological process in the conditions of a small enterprise or a small workshop of a restaurant establishment. An analysis of the implementation of the technological process of sterilization of canned goods in an electric autoclave was carried out on the created automated stand for controlling the electric autoclave under the name "Stand for automatic control and management of technological parameters of thermal equipment". Option of the modes of operation of the programmable logic controller OWEN PR200 with an electric autoclave are considered. The principle of operation of an electric autoclave in an electric circuit diagram with a programmable logic controller is given. The procedure for connecting sensors and their types, which participate in determining the parameters of a given technological process are considered. It was determined that the initial option, which is responsible for the beginning of research, is option №1, and the number of options is 18, which are programmed for specific values of the given technological process in the memory of the programmable logic controller. Methods of controlling the electric autoclave were defined directly through the display of the programmable logic controller or through the installed informative SCADA program on a personal computer. It has been previously established that the SIMP Light ENT SCADA system provides access via a local network or via the Internet to current and archived data of the technological process. It has been investigated that procedure for starting the SIMP Light ENT SCADA program is given the channel editor, checking the channel settings, selecting the desired COM port, starting test channels, the mnemonic editor, and starting the monitor. It has been experimentally proven that the heating of an electric autoclave is started either directly by a programmable logic controller or by a personal computer with a SCADA program. It has been investigated that the electric autoclave is heated during the time specified by the technological process to the specified parameters. It was determined that the parameters set by the technological process correspond to the values of the resistance thermometer and the pressure sensor for the corresponding technological process, to according option is No. 13 − sterilization of canned meat. Voltage fluctuations and non-stationarity of technological parameters within 2% were analyzed, which is associated with typical features of a programmable logic controller regulator, but the indicated indicators are within the norm.

Key words: *technological parameters, electrical equipment, operating modes of sterilization of canned meat, technological process, PLC automation, food product.*

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Introduction. The food industry plays an important role in meeting the needs of consumers by supplying raw and processed food products (Fauziah et al., 2020; Munirah et al., 2021). The food industry is now using cost-effective and profitable automation solutions (Chandrasiri et al., 2022) to achieve higher production volumes than the food industry using manual process control systems (Mishachev et al., 2020). Robotic processing and manufacturing are more popular now that the abandonment of manual labor is considered as a concept (Mokrushin, 2022). The food industry is more compatible with automation systems than any other industrial sector (Gordon, 2020). Automation is a technology related to the application of mechanical, electronic and computer systems for the management and control of production. Automation of control systems has revolutionized the food industry, enabling faster and more efficient production processes. As the demand for food products increases (Meshram et al., 2019), manufacturers are increasingly turning to automated production process controls to increase productivity, reduce production costs, and improve safety and quality standards. Overseas, the food industry is an important sector of the economy, generating over $2 trillion in sales in 2020, and that's just in beverages. The use of automation in the food production process has a number of advantages (Malaka, & Maruddin, 2020). Automated technological process management systems (ATPMS) reduce the risk of human errors, reduce the level of contamination of the technological process, and ensure compliance with food safety standards. Automatic control systems allow manufacturers to maintain stable product quality, minimize production waste, increasing its efficiency (Radchuk & Savchenko-Pererva, 2023). Also, automation technologies help reduce labor costs, allowing manufacturers to invest free money in other areas of their business (Savchenko-Pererva, 2022; Savchenko-Pererva & Radchuk, 2021).

Today's advances in automation technology lead to the development of competitive intelligent systems that can learn and adapt to different situations, increasing the efficiency and effectiveness of production processes.

Today, robots and automatic processes are considered an integral part of industry. Supply chain efficiency has become a priority for the food industry as it is a critical step in handling and managing actual demand rather than forecasted demand (Kalantzis & Revoltella, 2019; Nam & Chung, 2020). The automation system is mainly driven by the competitive success and safety of the food industry or manufacturing enterprise. The most valuable advantage of the automation system is the improvement of labor productivity, product quality and profitability (Kumar et al., 2020).

This article examines the impact of automation on the process of manufacturing canned food products, which controls the progress of the production process (Alvarenga et al., 2018).

Autoclaves play a key role in food storage and preservation processes, helping to ensure the safety and extend the shelf life of a variety of food products (Stier, 2019).

Autoclaves are commonly used in the canning industry to sterilize closed food cans (Triana et al., 2020). Jars filled with food products and sealed with lids are treated with high-pressure steam in autoclaves (Hartulistiyoso & Akmal, 2020). This process effectively kills bacteria, mold, yeast and other microorganisms, preventing spoilage and ensuring long-term food preservation (Wang et al., 2019). Autoclaves using high-pressure steam are widely used in large and medium-sized processing enterprises. For small enterprises, the use of steam is economically expensive and therefore autoclaves with electric heating are used. Such autoclaves are also subject to automation, which significantly affects the quality of finished products and prevents the negative influence of the human factor on the technological process.

Materials and methods of research. Conducting research on the automation of equipment for sterilization of canned food was carried out with the help of a special laboratory stand, Fig.1a.

This stand includes an electric autoclave and a technological process control and automation unit. Let's consider the components of the stand in more detail. The electric autoclave consists of a body, which is presented in Fig.1b, a cover with devices and a device for hermetic closure, Fig.1c.

The body of the autoclave is equipped with electric heaters for heating cans with canned food. The electric curtains used in the laboratory stand have a power of 2.2 kW and a nominal voltage of 50 Hz and 220 V. The tanks are located in the lower part of the autoclave and separated from the other part by a special perforated metal partition. Water moves freely through the perforation of this partition. This partition is used to install cans with canned food on it, which must be subjected to the sterilization process. Capacity of the laboratory stand: 8 cans of 0.5 liters or 5 cans of 1.0 liters. In the upper part of the autoclave body there is a neck, on which the cover is installed and with the help of a device for hermetic closure, the internal environment of the autoclave is sealed. A rubber seal is placed between the cover and the neck for reliable sealing of the connection. The device for hermetic closure is a screw with a handle that engages with

a b c

Fig. 1. A stand for conducting research on the automation of equipment for the technological process of sterilization of canned goods in an electric autoclave: a – a general view of the stand; b – body of the electric autoclave; c – the lid of the autoclave with devices and a device for hermetic closure

a nut. The nut, in turn, has three rigidly attached elongated rectangular rods that, when the autoclave is closed, engage with three rods that are rigidly attached around the neck of the autoclave. Thus, when the screw is turned, it moves towards the neck of the autoclave body and rests against the lid, sealing the autoclave.

Devices are installed on the lid of the autoclave:

− safety valve designed for a maximum pressure of 600 kPa. This valve is used to prevent exceeding the maximum pressure inside the autoclave;

− control manometer with the maximum ability to measure pressure of 400 kPa. It is used to visualize and control the progress of the technological process;

− resistance thermometer DTS 0.1 5-50 M.V.2.80, which allows you to measure the actual temperature inside the autoclave and transmit information to the controller. The resistance thermometer has a measuring range: -50...+180 °C;

− pressure sensor PD 100-DY 0.25-171. The maximum excess pressure measured by the sensor is 250 kPa (short-term up to 400 kPa). This sensor converts excess pressure into a unified 4...20 mA direct current signal. The resistance sensor is connected to the controller and transmits real-time information about the excess pressure inside the autoclave.

Thus, the autoclave has the ability to heat up with the help of electric current and transmit the actual temperature and overpressure readings to the controller.

The unit of control and automation of the technological process of sterilization of canned goods has a programmable controller OWEN PR200 in its composition. The OWEN PR200 controller has the ability to program to execute a certain sequence of commands. In its design, it has terminals for connecting external devices, such as a resistance thermometer and an excess pressure sensor. Also, the design of the controller provides for the presence of switches that are turned on and off under certain conditions according to the program entered in the controller's memory. The controller provides a connection via a USB 2.0 port to a personal computer. Through this port, the process control program, which is created in the specialized OWENLOGIC software environment, is loaded into the controller. Controller operation is controlled using a personal computer and SIMP Light ENT special software. The technological process of sterilization of canned goods is accompanied by a change in the temperature inside the autoclave, the form of the graph of which can be represented as a dependence of temperature t, °C on time T, min, t = f(T), Fig.2.

The dependence graph t = f(T) has three zones:

− I – a zone of intense heating from the temperature of the surrounding air to the sterilization temperature of this product t_{st}. Intensive heating takes place over time from 0 to Tn − the time when the product is kept at a constant temperature;

− II – a zone of exposure to temperature t_{st} during a certain period from Tn to Tex, which depends on the type of product and the size of the can in which the product is located;

− III – the cooling zone of the sterilized product.

You can control the change in temperature in the autoclave by turning on and off its electrical elements to the alternating current network. This happens with the help of a switch controlled by the OWEN PR200 controller.

The general process of conducting research on the automation of equipment for the technological process of sterilization of canned goods is as follows:

1. It is necessary to connect the autoclave with the controller, according to the automation scheme, Fig. 3.

2. In the middle of the autoclave, we install cans with canned food. Pour water into the middle of the autoclave to a level that covers the cans with a layer of at least 2 cm.

3. We connect the controller and the autoclave to the 220 V, 50 Hz alternating current network. We also turn on the personal computer, having previously connected it to the controller via the USB 2.0 port.

4. We launch the SIMP Light ENT program on a personal computer. The indicators of the technological process are displayed on the monitor screen, Fig. 4.

5. On the screen of the personal computer monitor, with the "mouse" manipulator, using the buttons "Choice option+1", "Choice option-1", "Reset", select the program number. A total of 18 programs have been developed and loaded into the OWEN PR200 controller. The programs differ among themselves in terms of the numerical value of the sterilization temperature t_{st}, °C and the exposure time T, min. Accordingly, it is possible to choose the sterilization temperature from the following series: 100, 110, 115, 120 and the exposure time from the series: 10, 15, 20, 30,

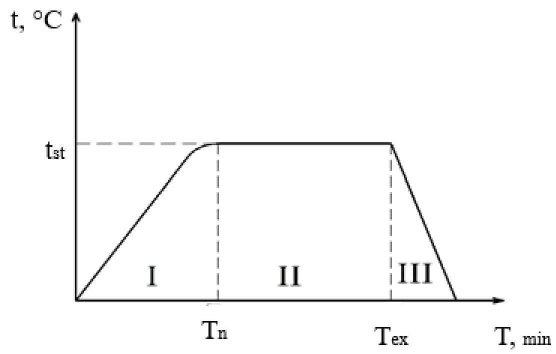


Fig. 2. Dependence of temperature t, °C on time T, min during sterilization of canned goods in an autoclave

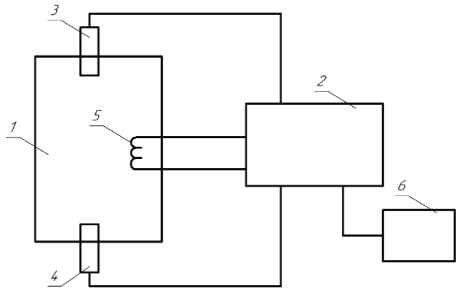


Fig. 3. Electric autoclave automation scheme: 1 – autoclave; 2 – controller; 3 – pressure sensor; 4 – resistance thermometer; 5 – electric tan; 6 – person computer

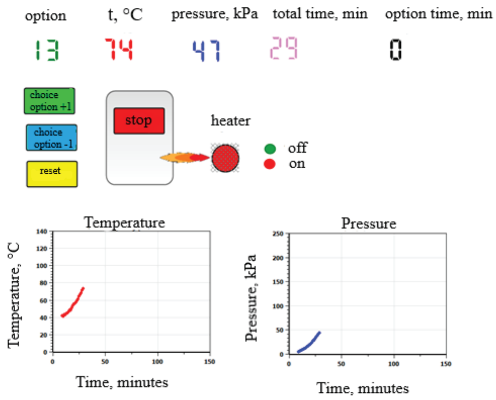


Fig. 4. General view of the SIMP Light ENT program for automating the control of the technological process of sterilization of canned goods in an electric autoclave

40, 50, 60, more than 60. After selecting the program, the OWEN PR200 controller automatically switches to mode of its execution, the switch on the controller is turned on and alternating voltage is applied to the autoclave's electric shades. The number of the program variant, the temperature in °C and the pressure in kPa inside the autoclave, the total time of the program execution in minutes are indicated on the personal computer screen in real time. Also, graphs of the dependence of temperature on time t= f(T) and pressure on time P = f(T) are automatically built on the screen of a personal computer. This information can be exported in numerical form for use in drawing graphs in MS Excel.

6. At the end of the program execution time, the controller turns off the electric current supplied to the autoclave trays. The process of cooling the autoclave and unloading the finished product takes place. The technological process is completed.

Results. In order to carry out a practical study, the automation of the equipment for the technological process of sterilization of canned meat was carried out. Canned meat was placed in cans with a capacity of 0.35 liters, closed and placed in the middle of the autoclave. Water was poured into the autoclave 2 centimeters above the level of the cans. The autoclave was hermetically closed with a lid. According to Fig.3, the automation scheme was assembled. The next step was to turn on the personal computer and the controller, select program mode No.13 (table 1) in accordance with the raw material. For this option, the heating takes place to the sterilization temperature t_{st}=120 °C with a duration of 20 minutes.

After selecting the program, the controller automatically started its execution. The temperature and excess pressure inside the autoclave are displayed in real time on the computer screen. These indicators are fixed.

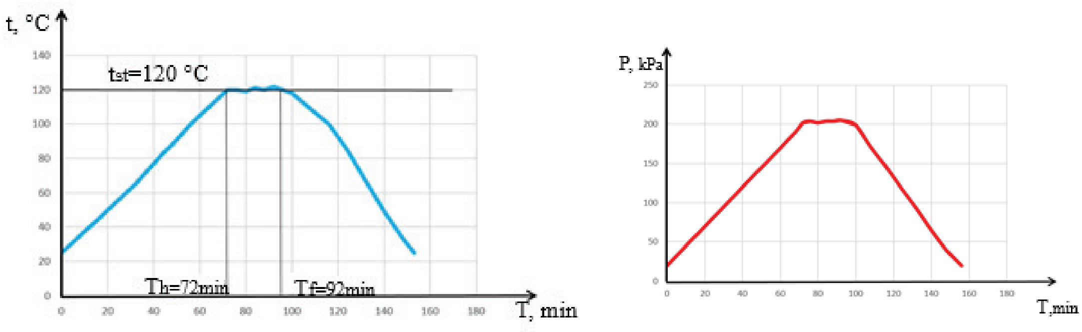
According to them, graphs of the dependence of temperature on time t = f(T) Fig.5a and pressure on time P = f(T), Fig.5b were constructed. Temperature is measured in °C, excess pressure is measured in kPa.

Analyzing the graphs, you can distinguish 3 zones on them. The first zone is the heating zone of the autoclave to the sterilization temperature 72 °C. This heating takes 72 minutes (T_h). At the same time, the excess pressure in the autoclave increases from 20 kPa to 200 kPa. This pressure allows water not to boil at a temperature of t_{st}=120 °C. The second zone is a zone of exposure for 20 minutes. This happens from 72 to 92 minutes of the technological process of sterilization. As you can see, the temperature inside the autoclave is within 119...122 °C. Such a change in temperature is caused by the fact that the water is heated by electric heaters and there is a certain inertia of the thermal system. The electric tan is heated from the current to a much higher temperature than 120 °C, then the heat released by the tan is transferred to the water, which in turn heats the jar with the food product and the temperature sensor. As soon as the temperature sensor has recorded 120 °C, the electric heater is turned off by the OWEN PR200 controller, but the

Table 1

Autoclave operating modes

Option No.	Sterilization temperature t, ºC	Exposure time T, minutes
1	100	10
2	100	15
3	100	20
4	100	more 20
5	110	20
6	110	30
7	110	40
8	110	more 40
9	115	20
10	115	25
11	115	30
12	115	more 30
13	120	20
14	120	30
15	120	40
16	120	50
17	120	60
18	120	more 60



a　　　　b

Fig. 5. Dependence graphs: a – temperature t = f(T); b – pressure P = f(T) from the time of execution of the technological process of sterilization in an electric autoclave

internal thermal energy accumulated by the body of the electric heater will be transferred to the water. Therefore, the water begins to overheat to 122 °C. Accordingly, the value of the water temperature of 119 °C occurs as a result of the fact that the water cools down to this temperature, only after that the controller will re-connect the electric power to the tank, and the heating will be repeated. The third zone on the chart is at a time of more than 92 minutes (T_f). At this time, the controller turned off the supply of electrical energy to the autoclave tank and the process of autoclave cooling takes place.

Discussion. On the basis of the conducted research, it can be stated that the automated stand for control and management of an electric autoclave using a programmed logic controller is adequate. The technological process of sterilization of canned meat takes place with the help of an electric autoclave and an OWEN PR200 connected to a personal computer with a special SIMP Light ENT software product. Comparing the stability and stationarity of our proposed technological process with the technological processes in the autoclave of other authors, we can conclude that we have achieved reliable results. Thus, in her chapter of the manual, Susan Featherstone presented the calculations of the heating parameters of the sterilization process, which, according to the table of options for existing processes, coincide with ours. R. Malaka, A. Triana and G. Ghoshal proposed a method of sterilizing milk with the addition of extract in the same equipment as in our article – an electric autoclave that works on the same principle (Malaka & Maruddin, 2020; Triana et al., 2020; Ghoshal, 2018). S.Piramuthu, E. Saldaña, G. Saravacos and S. Featherstone substantiated the feasibility of using an electric autoclave for food preservation (Piramuthu & Zhou, 2016; Saldaña et al., 2013; Saravacos & Kostaropoulos, 2016; Featherstone, 2015). R.-Y. Chen, K. J. Jijo, K. K. Sandey, L. Pan and W. L. Lau in their works investigated the dependence of temperature on the condition of canned products sterilized in autoclaves at high pressure (Chen, 2017; Chen, 2016; Jijo & Ramesh, 2014; Sandey et al., 2017; Pan et al., 2017; Lau et al., 2015). Their conclusions regarding the research are identical to ours, since the pressure exerted upon reaching the required temperature during canning of poultry meat in an electric autoclave did not exceed the norm and increased at a proportional rate to the temperature. M. Muller, R. Chaari, J. Iqbal and H. A. Pierson in his publication emphasizes the necessity and expediency of using robotic systems in the world (Muller et al., 2014; Chaari et al., 2016; Iqbal et al., 2017; Pierson & Gashler, 2017). And scientists E. Hartulistiyoso and M. Akmal studied the canning of crab meat in a capacity of 0.35 liters, which determines the standard indicator of the volume of cans for canning in the food industry (Hartulistiyoso & Akmal, 2020).

Conclusions. As a result of the conducted research, it was proposed to use an electric autoclave with a programmable controller OWEN PR200, which made it possible to automate the technological process of sterilization of canned goods. For the first time, the software product developed and loaded into the OWEN PR200 controller using a personal computer and specialized OWENLogic software allows you to have 18 program options in which the parameters of the sterilization process are programmed, such as the sterilization temperature: 100 °C, 110°C , 115 °C, 120 °C and time durations: 10, 15, 20, 30, 40, 50, 60 and more minutes. The choice of such indicators of the technological process allows sterilization of canned meat and vegetables in cans with a capacity of 0.35 liters; 0.5 liters; and 1.0 liters. The main parameters of the technological process of sterilization are indicated in real time on the screen of a personal computer in the SIMP Light ENT program. It is also possible to record these parameters and export them to MS Excel.

The practical application of the obtained results consists in the complete automation of the technological process of sterilization of canned goods in an electric autoclave, which allows the reproduction of the process any number of times while preserving the technological parameters of the process. And there is also an opportunity to conduct new scientific research on the optimization of the parameters of the technological process of sterilization and the preparation of new types of canned goods with controlled parameters.

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Автоматизація керування електричним автоклавом

У статті проаналізовано використання електричного автоклава із запропонованою системою автоматизованого керування технологічним процесом в умовах малого підприємства або невеликого цеху закладу ресторанного господарства. Проведено аналіз виконання технологічного процесу стерилізації консервів в електричному автоклаві на створеному автоматизованому стенді керування електричним автоклавом під назвою «Стенд автоматичного контролю та керування технологічними параметрами теплового устаткування». Розглянуто варіанти режимів роботи програмованого логічного контролера ОВЕН ПР200 з електричним автоклавом. Наведено принцип роботи електричного автоклава у схемі електричного ланцюга з програмованим логічним контролером. Наведено порядок підключення датчиків та їх види, що беруть участь у визначенні параметрів заданого технологічного процесу – термометр опору, для визначення значення температури та датчик тиску. Визначено, що початковим варіантом, який відповідає за початок проведення досліджень, є варіант №1, а кількість варіантів – 18, що запрограмовані під конкретні значення заданого технологічного процесу в пам'яті програмованого логічного контролера. Визначено способи управління електричним автоклавом – безпосередньо через дисплей програмованого логічного контролера або через встановлену інформативну програму SCADA на персональному комп'ютері. Попередньо з'ясовано, що SCADA система SIMP Light ENT забезпечує доступ по локальній мережі або *через Інтернет до поточних та архівних даних технологічного процесу. Підтримується робота Монітора в мережевому режимі – можливе підключення кількох ПК до однієї станції. Наведено порядок запуску програми SCADA система SIMP Light ENT – редактор каналів, перевірка налаштування каналів, обрання потрібного COM порт, запуск тестових каналів, редактора мнемосхем та запуск монітора. Експериментально доведено, нагрівання електричного автоклава запускається за рахунок або безпосередньо програмованим логічним контролером, або персональним комп'ютером з програмою SCADA. Досліджено, електричний автоклав нагрівається протягом зазначеного технологічним процесом часу до заданих параметрів. Визначено, що задані технологічним процесом параметри відповідають значенням термометра опору та датчика тиску для відповідного технологічного процесу, відповідно до обраного варіанту – варіант №13 – стерилізація м'ясних консервів. Проаналізовано коливання напруги та нестаціонарність технологічних параметрів в межах 2%, що пов'язано з типовими ознаками регулятора програмованого логічного контролера, але зазначені показники – в межах норми.*

Ключові слова: *технологічні параметри, електрообладнання, режими роботи стерилізації м'ясних консервів, технологічний процес, автоматизація ПЛК, харчовий продукт.*