Automated Systems & Technologies
25-26 May 2015 • St. Petersburg, Russia

THE AUTOMATED TECHNOLOGICAL COMPLEX ON PROCESSING OF RUBBER PRODUCTS.

Goppe G.G., Dunayev M.P., Kirgin D.S.

"Irkutsk national research technical university"
Lermontov St., 83.
664074, Irkutsk, Russia
kirgind@yandex.ru

Abstract
This paper contains the description of the process of heat treatment of the rubber products under pressure in the automated technological complexes (autoclave), the presentation of the mathematical description of the process, the experimental data and the comparison of mathematical calculations and the experimental data.

INTRODUCTION

The present stage of development of the world economy is characterized by a significant increase in the production and consumption of energy resources. The depletion of natural sources and significantly increased costs of production and transportation ultimately led to the rapid increase in energy prices. Most of the energy is produced from non-renewable sources, therefore introduction of energy saving technologies is increasingly urgent.

Production efficiency in modern industries is achieved with a clear and coordinated work of all parts of the production process, which is done only on the basis of complex automation of production processes. It fully applies to the technological complex for thermal treatment of rubber parts under pressure, which widely use industrial autoclaves.

GENERAL

The first part of technological process in an autoclave (which is called vulcanization) is placing rubber products in the machine. After that autoclave gets pressurized. According to the technological requirements the machine gets supplied with steam and air with the corresponding parameters. Control modes of the autoclave was reduced to the mentioned management of material flows so as to provide the necessary rise of pressure and temperature, and their stabilization. Until recent time technological process was coped in the manual mode and was rather energy-intensive. Quality of management was poor.

To obtain the required quality of product processing and energy reductions in the autoclave the process of vulcanization was automated using flexible regulation of pressure and temperature. This is achieved most effectively if you know the mathematical models of the processes of pressure rise, stabilization of temperature and pressure, as well as the nature of heat transfer processes in an autoclave. At the stages of increase and stabilization of the pressure in the autoclave a different value of counter pressure ($H_{вст}$) is set and, accordingly, the transition laws of water vapor in the condensate are different. Therefore, it was decided to simulate the processes of condensation with mathematical model based on the use of experimental data. The data convergence criterion, specified by experiment on the real installation and obtained by means of a mathematical model, is equality of amounts of pressure and steam. Fig. 1 shows an experimental plot of pressure and temperature on the supply amount of steam into the autoclave.

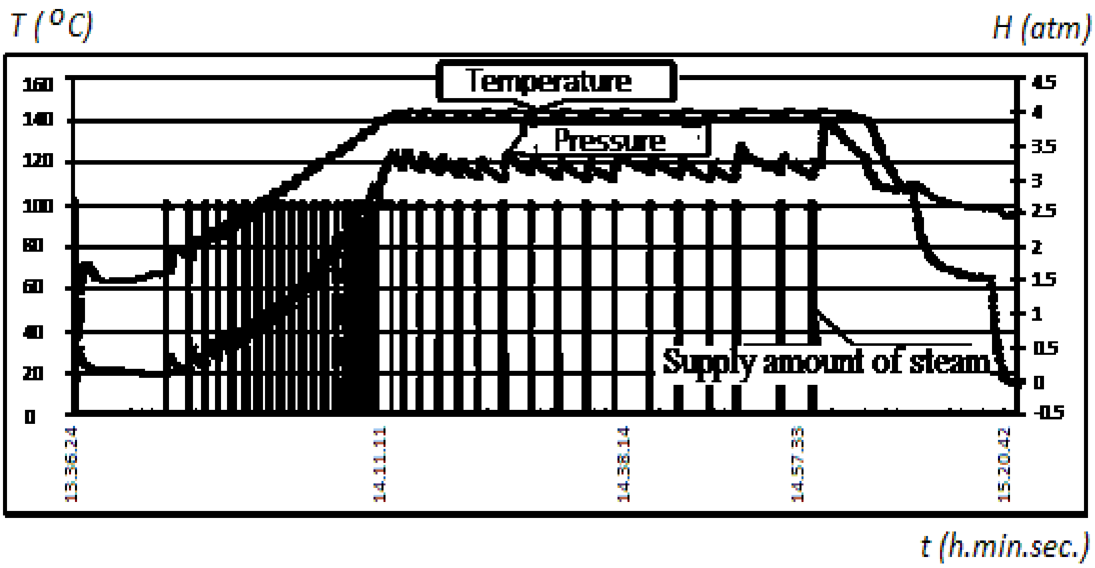

Figure 1. Temperature and pressure values of the steam in the autoclave

In [1], there is a mathematical model of the law of the ramp-up of air pressure in an autoclave at stabilizing the performance of air line, which implies the equation of motion of fluid flow and gas pipe line. The first version of the mathematical model is represented as an expression (1). It determines the pressure of steam through the movement speed in the pipeline. The second embodiment is a mathematical model (2), which determines the volume of steam supplied to the autoclave.

$$H = \left[1 + \lambda \frac{L}{D_{yc}} + \sum \xi_c + \xi_c(\bar{y})\right] \frac{V^2 \cdot \gamma}{2g}, \quad (1)$$

H - Pressure of the steam supplied from the manifold, Pa;

V - Vapor velocity in the pipe; γ - the proportion of steam;

$$H = \left[1 + \lambda \frac{L}{D_{yc}} + \sum \xi_c + \xi_a(\bar{y})\right] \frac{Q^2 \gamma}{2gS_{yc}^2} \quad (2)$$

S_{yc} - Area of the inner section of the pipeline; Q - Steam production.

It follows from (1) the contents of the bracket for a given autoclave has the form:

$$\left[1 + \lambda \frac{L}{D_{yc}} + \sum \xi_c + \xi_c(\bar{y})\right] = \frac{2g \cdot H}{V^2 \cdot \gamma} = \frac{2 * 9{,}8 \frac{м}{\sec^2} \cdot 500000 Pa}{(43 \frac{м}{\sec})^2 \cdot 2{,}607 \frac{кg}{м^3} \cdot 9{,}8 \frac{м}{\sec^2}} = 198{,}8$$

Since steam is supplied into the container and inside the pressure medium increases, the differential pressure is: $\Delta H = H - H_{вст}$, - pressure inside the autoclave. Using in combination with (2) the steam production Q, can be expressed:

$$Q = \sqrt{\frac{2g \cdot S_{yc}^2 \cdot (H - H_{вст})}{\left[1 + \lambda \frac{L}{D_{yc}} + \sum \xi_c + \xi_c(\bar{y})\right] \cdot \gamma}} = 0{,}0003106 \cdot \sqrt{\Delta H} \quad (3)$$

The resulting expression gives the possibility to calculate the mass of steam who came in the autoclave during the stabilization phase of temperature and pressure.

$$m_{пара} = Q \cdot t_{отк} \cdot \rho_{пара} = 0{,}0003106 \cdot t_{отк} \cdot \sqrt{\Delta H} \cdot 2.607 = 0{,}00081 \cdot \sqrt{\Delta H} \cdot t_{отк} \quad (4)$$

$t_{отк}$ - Time at which the steam valve is fully open.

Knowing the time of supply steam and the pressure in these inclusions, we can calculate the amount of steam fed during vulcanization. n [2] there is a mathematical model of the dynamics of the process of changing the flow rate of steam in an autoclave (5).

$$\frac{dQ}{dt} = \frac{\Delta H * S_{yc} * q}{L * \gamma} - \left[1 + \lambda \frac{L}{D_{yc}} + \sum \xi_c + \xi_a(\bar{y})\right] \frac{Q^2}{2LS_{yc}} \quad (5)$$

o compare the resulting mathematical model and the actual process of growth of steam in autoclave it is necessary to provide opening of the steam valve in the same mode as it was used on practice. The presence in the software environment. The presence of Signal Builder block in the programming environment Matlab: Signal Builder block provides the ability to simulate steam valve opening like at experiment. Fig. 2 is a chart of the provisions of the regulatory body, the corresponding values of the valve opening steam in an autoclave. The ordinate in Fig. 2 shows the value of the opening of the regulator in the case of steam supply control valve with pneumatic actuator: degree of opening will be equal to 100% (valve open) or 0% (valve closed). Along the horizontal axis in Fig. 2 shows the time in seconds.

In (1), (2) the value of a coefficient of hydraulic resistance of pipe fittings. In the case of transposition on the pipeline in and linear "internal data" fittings ratio for $\xi_a(\bar{y})$ defined: [3]. $\xi_a(\bar{y}) = \frac{20g \cdot S_{yc}^2}{(Q_{yc} \cdot \bar{y})^2}$, Q_{yc}- Conditional throughput pipeline fittings (valves) for water; $\bar{y}$- Relative position of the regulator. If $\bar{y} = 0$ then regulator body is fully closed, $\xi_a(\bar{y}) = \xi(0) = \infty$ and the productivity is equal to zero. If $\bar{y} = 1$, then regulatory body is fully open and the minimum value of the coefficient $\xi_a(y = 1)$. Valve on the autoclave by reference data $\xi_a(y = 1) = 0{,}3$. Using equation (6) to determine of conditional bandwidth pipeline fittings steam.

$$Q_{yc} = \sqrt{\frac{20g \cdot S_{yc}^2}{0{,}3 \cdot 1^2}} = 6{,}26 \frac{м^3}{\sec}$$

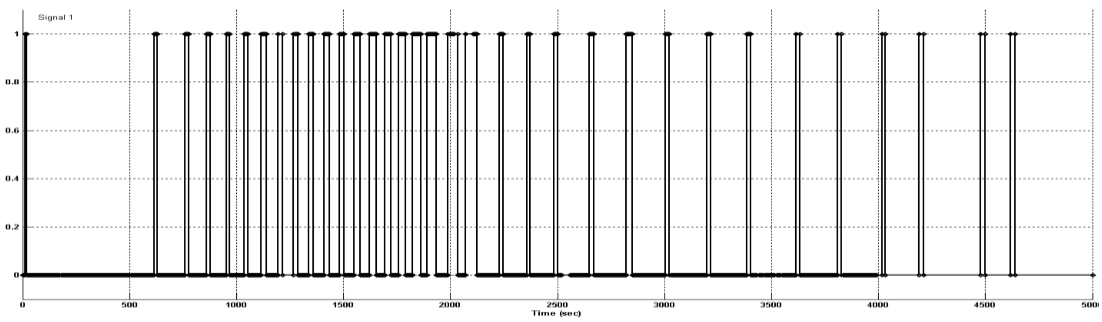

Figure 2. Diagram supply of steam in autoclave.

At Fig. 3. There is a block diagram of the process of changes of steam pressure in the autoclave (it was created in a software environment Matlab).

In the sector of "A" there is a mathematical model which describes the motion of gas flow in the pipelines in the dynamics.

Block "1" sets the regulatory body, the corresponding chart data steam autoclave (Fig. 2); Block "2" organizes record values Q_{yc}; Block "3" calculates the output value $\left[\left(1+\lambda\frac{L}{D_{yc}}+\sum\xi_c+\frac{20g\cdot S_{yc}^2}{(Q_{yc}\cdot\bar{y})^2}\right)\right]$; Block "4" calculates the value: $\left[\frac{1}{2LS_{yc}}\right]$; Block "5" calculates the value: $\left[\frac{S_{yc}\cdot q}{L\cdot\gamma}\right]$.

The technological process in autoclave occurs in two stages (rise in temperature and pressure and stabilization of these two values), with varying degrees of condensation of the incoming steam. In the first stage, when the temperature of the housing autoclave is low, the steam will condense actively. In the second stage of the vulcanization process, the temperature of housing of autoclave is high, so the condensation of steam decreases.

In the sector of "B" shows the model of the formation of condensate for the two stages above of the technological process. The time constants are chosen to satisfy the condition of conformity between the amount of steam and condensate and the quantity of steam and condensate, which were obtained by analyzing the experimental data. In block "6" is given the equation of pressure rise inside the autoclave: $P=\frac{1}{V}\int Q(t)dt$ (7)

$Q(t)$ - Consumption of steam at an absolute pressure; P- Pressure in the autoclave; V- Useful volume autoclave.

The volume of autoclave $V_{capacity}$=12,5 $м^3$.

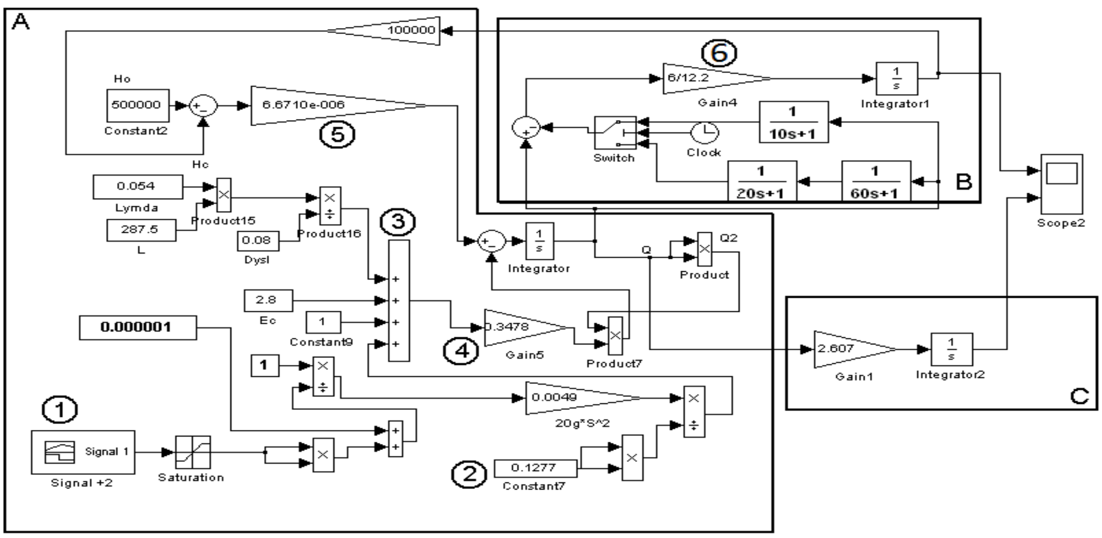

Figure 3. Model steam pressure changes in the autoclave.

One part of the autoclave capacity takes a trolley with profiles and rubber products, therefore useful volume will be smaller. Trolley with metal profile has a mass *m = 1200 kg*, the density of the material (Steel 20) $\rho = 7800\ \frac{\text{kg}}{м^3}$. Mass of rubber parts: *m = 100 kg*, the density of the material (synthetic rubber) $\rho = 7800\ \frac{\text{kg}}{м^3}$ [4]. Consequently; $V_{сттали20} = \frac{1200}{7800} = 0{,}15\ \ (м^3)$; $V_{резины} = \frac{100}{1230} = 0{,}08\ \ (м^3)$. Useful volume will be equal to: $V = 12{,}5 - 0{,}15 - 0{,}08 = 12{,}27\ \ (м^3)$. Fig. 4 block diagram of the sector "B" (Fig. 3).

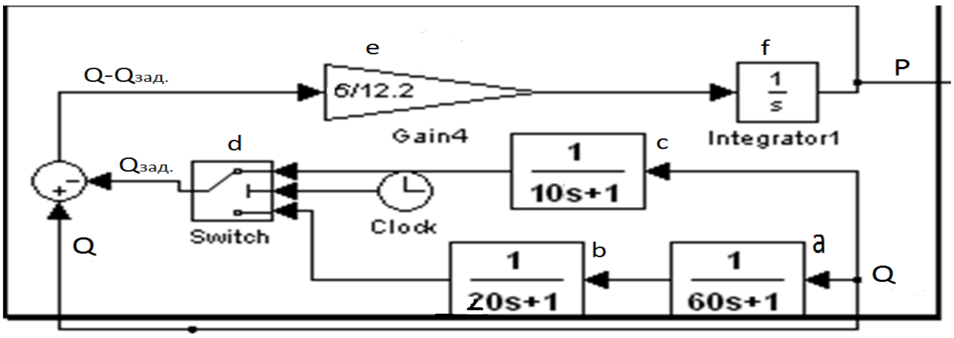

Figure 4 block diagram of the sector "B"

Fig. 4 shows that the condensation of steam and rise of pressure as follows: steam *Q* is input in aperiodic links a, b and c. Block *d*«Switch» is the key which switches from a lower position (signal units *a* and *b*) on the top (signal *c*) at the moment when the process duration is equal *t = 2100 sec*. Aperiodic links form a condensate volume $Q_{конд}$, which is deducted from the value of steam flow *Q*. Signal $Q - Q_{конд}$ fed to the input of the *"e"*, which implements the equation: $dP = \frac{6}{V}\int[Q - Q_{конд}](t)dt$.

Sector "C" includes a block density of steam. ($\rho = 2{,}607\ \frac{\text{kg}}{м^3}$) [5], fed to its input steam flow ($Q\ \frac{м^3}{\text{sec}}$), changing in time. Then the signal is integrated and obtained the quantity steam on output sector , which is received during the process ($m_{пара}$ kg).Fig. 5 shows two graphs: upper one shows the increase in the steam pressure in the autoclave; lower one - the amount of steam released to the autoclave cycle for vulcanization. We obtain the following results by comparing the mass of steam that was was actually received in the autoclave and the data of mathematical models of the process.

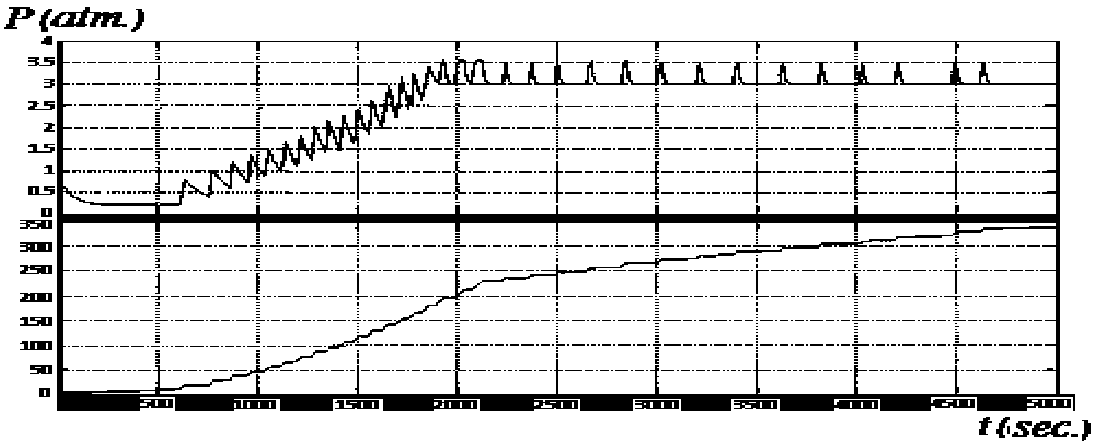

Figure 5. Graphs of pressure increase in the autoclave and the amount of steam released to the autoclave.

At the end of the first part of the cycle (*t = 35 min = 2100 sec*) the error is 4.01% (experimental data - *232.9 kg*; modeling - *223.9 kg*); at the end of the whole cycle of error is *0.9%* (experimental data - *342.3 kg*; modeling - *339.1 kg*). Diagram of the pressure, during the process with the use of method for controlling vulcanization in the autoclave is shown in Fig. 6 and marked with the number "2". The research model (Fig. 3) was obtained by changing the pressure graph shown in Fig. 6 and marked by the number "1". The graph of the pressure during the actual vulcanization process is marked with "2" in Fig. 6.

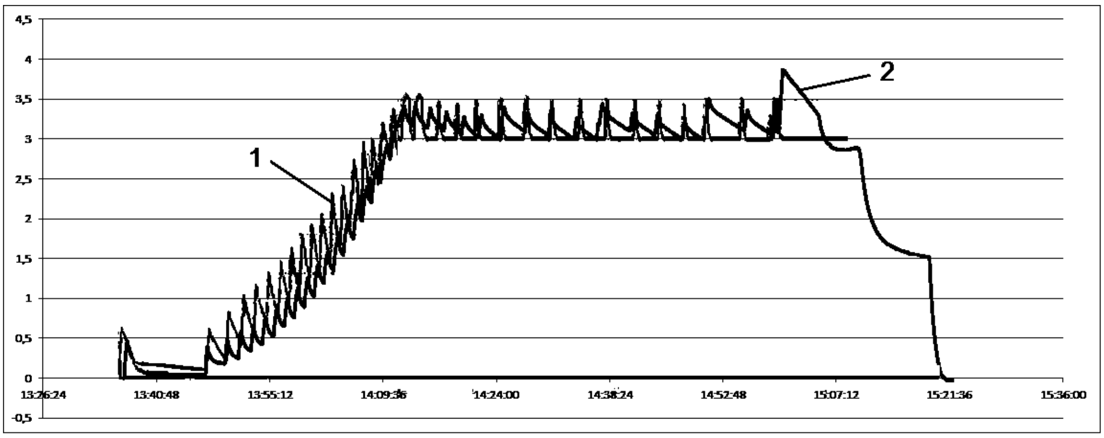

Figure 6. Graphs of change pressure: 1 - resulting in mathematical modeling, 2 - Definitions in the actual vulcanization process.

The graphs of Fig. 6 are the qualitatively similar, despite the fact that the quantitative discrepancy between the experimental and model graphs of pressure, estimated by the mean square error was 4%.

This gives the right to consider that the developed mathematical model of change of steam pressure in vulcanization process, adequately reflect the real process.

The amounts of steam spent in vulcanization process during manual adjustment had been calculated using the experimental data of the temperature and pressure. Steam consumption was 687 kg, but after the introduction of automation, mass of steam consumption dropped to 342 kg. Therefore the use of automation lowered the steam consumption in more than two times.

CONCLUSIONS

During the development of the automated technological complex for processing rubber products the following tasks have been resolved:

The mathematical models of the process control system of heat treatment of rubber products in an autoclave with steam heating method in the regulation of pressure and temperature, taking into account the relationship between these two parameters are developed.

The development of the mathematical models of the process control system of heat treatment of rubber products in an autoclave with steam heating method in the regulation of pressure and temperature, taking into account the relationship between these two parameters.

The development of the algorithms of the automated control system for complex heat treatment of rubber products.

• The development of the method of calculation of the autoclave equipment for process control vulcanization using steam heating.

• Autoclave AVTM 2000-4000-12.5. was automated at the Irkutsk Aviation Plant ("Corporation" Irkut ")

Automated control system of the autoclave allowed to save twice as much energy as there used to be due to the precision of algorithms technological regime; quality assurance process by accurately maintaining the temperature and pressure inside the autoclave; increase resource autoclave by compliance process more accurate operation.

REFERENCES

[1]. Goppe GG, Kirgin DS Mode control changes the gas pressure in an autoclave. Vestnik IrGTU №4 (63). 2012. p. 163-168.

[2].Goppe GG Danube MP, Kirgin DS A mathematical model of the process of changing the steam pressure in the autoclave. / In the writings of the Russian scientific-practical. Conf. "Improving the efficiency of the production and use of electric power in Siberia." - Irkutsk: Irkutsk State Technical University, 2013. - S.25-30.

[3]. Hoppe GG A mathematical model of fluid flow in pipes as a link CAP // Automation of chemical production, NIITEKHIM №4 - Moscow, 1973. - p. 32-43.

[4]. Kuznetsov DA General chemical technology. - M .: Higher School, 1970.

[5]. Vukalovic MP Thermodynamic properties of water and water steam.- M .: Energoatomizdat, 1999.