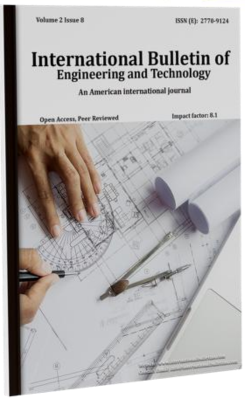

INVESTIGATION OF AN AUTOMATIC TEMPERATURE CONTROL SYSTEM FOR AN AUTOCLAVE REACTOR IN SCLAIRTECH TECHNOLOGY

Jabborov A.O.
Bekmurodov Q.Sh.
Abdirayimov X.A.
Email: quvonchbekbekmurodov7@gmail.com
Tel:+998935338061
https://doi.org/10.5281/zenodo.18239770

Annotatsion.

This paper investigates the automatic temperature control system of a high-pressure autoclave reactor of the DC-2101 type used in Sclairtech technology. In autoclave reactors, the ethylene homopolymerization process is strongly exothermic; therefore, temperature stability is of critical importance for ensuring product quality and technological safety. Within the scope of the study, the dynamic behavior of the reactor temperature was described using a mathematical model based on heat balance equations, and a computer model was developed in the MATLAB/Simulink environment. Automatic temperature regulation was implemented using a closed-loop control system with a proportional–integral (PI) controller. Simulation results obtained for various PI controller parameter settings enabled analysis of the reactor temperature transient responses and assessment of stability and control performance. The results demonstrate that, with optimal PI controller tuning, the reactor temperature can be maintained smoothly, rapidly, and without oscillations around the specified operating setpoint. The findings provide a scientific and practical basis for the design and industrial application of automatic temperature control systems in high-pressure autoclave reactors.

Keywords: *Autoclave reactor, Sclairtech technology, ethylene homopolymerization, automatic temperature control, PI controller, high-pressure reactor, MATLAB/Simulink, transient process, automatic control system.*

Introduction.

In high-pressure polymerization processes, stable and accurate control of technological parameters plays a crucial role in ensuring the continuity of industrial production and maintaining product quality. In particular, ethylene homopolymerization processes carried out in autoclave-type reactors are characterized by high energy release and exhibit strong sensitivity to the temperature regime. For this reason, the application of automatic temperature control systems in such processes is considered essential from the standpoint of technological safety and operational stability.

Under practical industrial conditions, ethylene homopolymerization in high-pressure autoclave reactors is conducted within a temperature range of $150\text{–}300\ °C$. This range is selected depending on the required grade of the product and the conditions necessary for stable process operation. At elevated temperatures, the probability of thermal degradation of polymer chains increases; therefore, in industrial practice, $300\ °C$ is adopted as the maximum allowable temperature limit. Under these conditions, maintaining the reactor temperature within specified bounds directly depends on the effectiveness of the automatic control system.

The polymerization process in autoclave reactors is strongly exothermic, and the heat released inside the reactor can lead to rapid temperature fluctuations. In such situations,

IBET | Volume 6, Issue 01, January

manual control methods are unable to provide sufficient accuracy and may pose a threat to technological safety. Consequently, closed-loop automatic control systems are widely employed in industrial practice to regulate reactor temperature.

Due to the large thermal capacity and relatively slow dynamic response of high-pressure autoclave reactors, the use of proportional–integral (PI) and, where necessary, proportional–integral–derivative (PID**)** controllers is considered appropriate for automatic temperature control. PI controllers demonstrate high reliability in eliminating steady-state error and ensuring stable operating conditions, whereas PID controllers offer the capability to compensate for abrupt temperature changes in advance. The selection of the controller type is based on the thermal characteristics of the reactor, the efficiency of the cooling system, and specific technological requirements.

In this study, issues related to automatic temperature control in the DC-2101 autoclave reactor are examined. The general structural configuration of the DC-2101 autoclave reactor is presented in Figure 1. The results of the study are intended to contribute to maintaining stable reactor temperature conditions, improving product quality, and ensuring the safety of the technological process.

Materials and methods.

In this study, a high-pressure autoclave-type reactor of the DC-2101 model was selected as the control object. The reactor is designed for the industrial implementation of the ethylene homopolymerization process and operates continuously under high temperature and pressure conditions. In industrial practice, ethylene homopolymerization is typically carried out within a temperature range of $150–300\ °C$. To ensure process stability, optimize the physicochemical properties of the product, and limit the risk of thermal degradation, an average operating temperature of $225\ °C$ was adopted as the main technological regime in this study. The general structural configuration of the DC-2101 autoclave reactor is shown in Figure 1.

Figure 1. DC-2101 Autoclave Reactor

Reactor temperature control was implemented using a closed-loop automatic control system. The controlled variable was the temperature of the reactor internal medium, while the manipulated variable was the flow rate of the cooling agent. The temperature was measured using high-accuracy industrial sensors and continuously transmitted to the automatic controller. This control configuration enabled effective compensation of the heat released by the strongly exothermic polymerization reaction occurring inside the reactor and ensured stable maintenance of the temperature around the specified operating setpoint.

Due to the large thermal capacity of the autoclave reactor and its relatively slow dynamic temperature response, a proportional–integral (PI) controller was employed for automatic temperature control. The choice of a PI controller was justified by its high stability when applied to thermal processes, its ability to completely eliminate steady-state error, and its effectiveness in providing smooth transient responses. Controller parameters were selected by taking into account the static and dynamic characteristics of the reactor, using experimental tuning methods.

The dynamic behavior of the reactor temperature was modeled based on simplified heat balance equations. In accordance with commonly applied approaches in industrial automation, the control object was represented as a first-order aperiodic system with time delay. After linearization, the transfer function of the controlled object was expressed as:

$$G(s) = \frac{K}{Ts + 1} \cdot e^{\tau s}$$

where K represents the static gain of the controlled object, T denotes the time constant, and τ corresponds to the transport delay. The transfer function of the PI controller used for automatic temperature regulation is given by:

$$G(s) = K_p(1 + \frac{1}{T_i s}$$

and was expressed in the above form. The mathematical model of the control system was developed by taking into account the reactor heat balance and its dynamic characteristics and was implemented in the MATLAB/Simulink software environment. The model represents a closed-loop automatic control system in which the controlled object, the PI controller, the measurement chain, and the cooling circuit are interconnected. During the simulation, the transient responses of the reactor temperature were analyzed under various initial conditions and external disturbances, and the system stability, transient duration, and steady-state error were evaluated. The obtained results demonstrate that the PI-controller-based control system is capable of maintaining the reactor temperature stably around the specified operating setpoint and contributes to ensuring process safety. The computer model of the automatic temperature control object developed in the MATLAB/Simulink environment is shown in Figure 2.

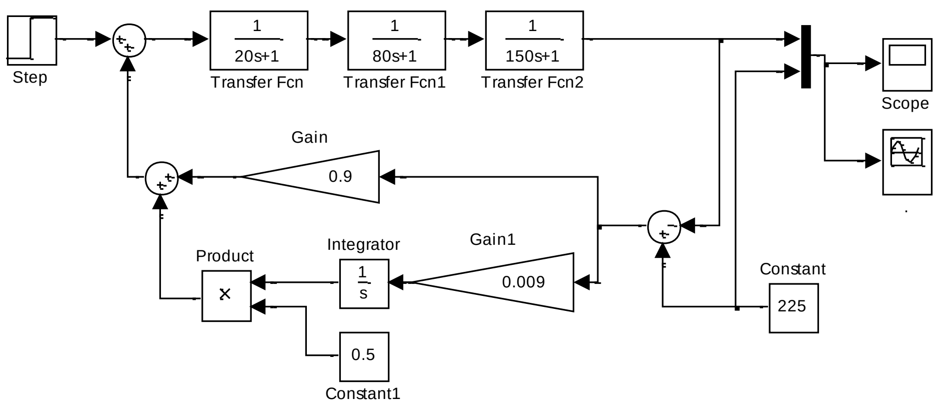

Figure 2. Computer model of the controlled object

IBET | Volume 6, Issue 01, January

To ensure the reliability of the simulation results, the physical meaning of the model parameters was verified, and the response characteristics of the temperature control loop were compared with the expected dynamic behavior of the technological process. The evaluation criteria included maximum deviation during the transient response, settling time, steady-state error, and stability margins. Based on these criteria, the PI controller parameters were optimized. In addition, taking into account the thermal inertia of the reactor and the effectiveness of the cooling circuit, the conclusions derived from the model were assessed in terms of their applicability under real industrial conditions. This methodological approach establishes the necessary computational and modeling basis for the design and practical tuning of an automatic temperature control system for the DC-2101 autoclave reactor.

Results.

Within the scope of this study, modeling and simulation activities carried out in the MATLAB/Simulink environment enabled a comprehensive evaluation of the dynamic characteristics of the automatic temperature control system for the DC-2101 high-pressure autoclave reactor. Using the developed model, the time evolution of the reactor temperature, the shape and duration of transient processes, and the sensitivity of the control system to external disturbances were analyzed. In particular, the effects of additional heat loads arising from the exothermic nature of the polymerization process and variations in cooling conditions on the temperature regime were assessed through simulation.

The results of the simulations focused on assessing the capability of the PI-controller-based automatic control system to maintain the reactor temperature stably around the specified operating setpoint. Based on the transient response plots obtained under various initial conditions and disturbance scenarios, system stability, smoothness of the control action, response time, and steady-state deviation were evaluated. These analyses made it possible to determine the impact of the selected PI controller settings on process stability and to substantiate the practical effectiveness of this control approach for automatic temperature regulation in high-pressure autoclave reactors.

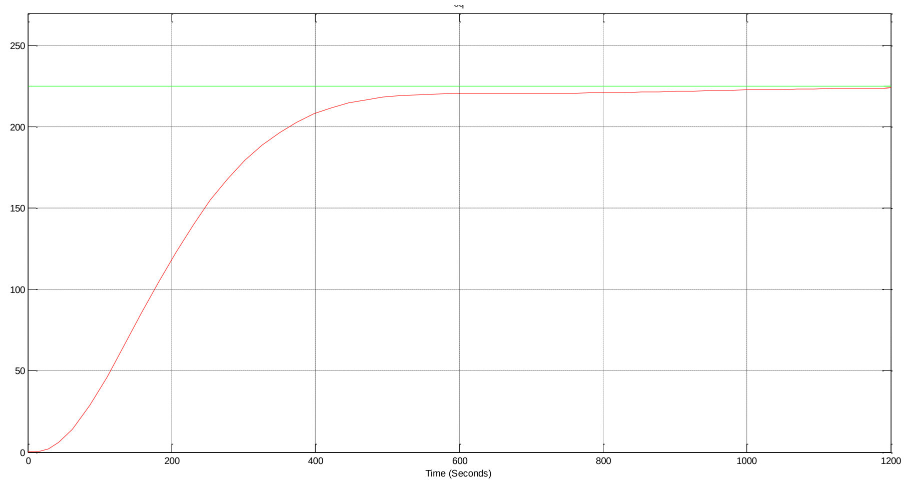

Figure 3. Transient response of the reactor temperature under aggressive PI controller settings (gain $K = 0.9$, integral time $Ti = 0.009$)

In the graph shown in Figure 3, the PI controller is configured with a relatively low proportional gain and a very short integral time. As a result, the system responds rapidly to temperature variations; however, due to the insufficient proportional action, the control signal is unable to fully compensate for the large thermal inertia of the reactor. As can be observed from the graph, the reactor temperature approaches the desired setpoint gradually, exhibiting a smooth increase in the initial phase, while the overall settling time remains relatively long. Although this controller setting ensures stable operation, it does not provide sufficient dynamic performance for the technological process and is therefore considered limited from the standpoint of maintaining the reactor at an optimal operating regime.

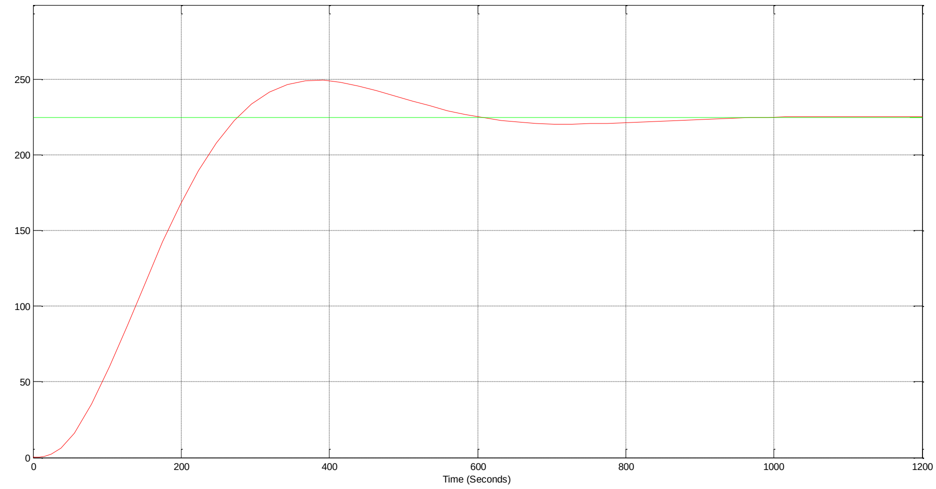

Figure 4. Transient response of the reactor temperature under aggressive PI controller settings (gain K=1.15, integral time $Ti = 0.0156$)

In the graph presented in Figure 4, the proportional gain is increased and the integral time is slightly enlarged. Under these conditions, the PI controller responds more actively to deviations in the reactor temperature. As observed in the graph, a slight overshoot beyond the setpoint occurs, after which the temperature decreases and stabilizes around the operating value. This behavior can be attributed to the strengthened integral action of the controller. Overall, the system exhibits improved responsiveness; however, the onset of oscillatory behavior becomes noticeable, which should be carefully evaluated for thermal processes where excessive temperature fluctuations may be undesirable.

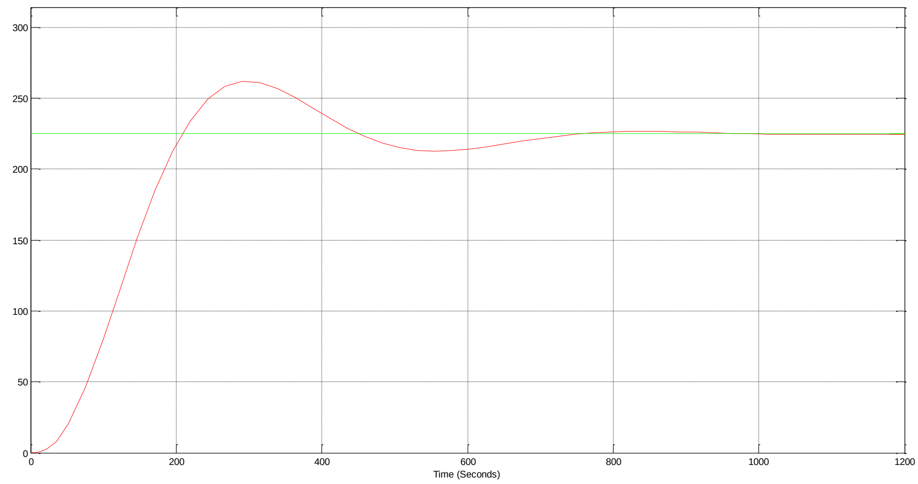

Figure 5. Transient response of the reactor temperature under aggressive PI controller settings (gain $K = 1.94$, integral time $Ti = 0.0189$)

In the graph shown in Figure 5, the PI controller is tuned in a more aggressive manner. A significant increase in the proportional gain causes the reactor temperature to reach the desired setpoint very rapidly. However, the graph clearly indicates that this increased responsiveness is accompanied by a pronounced overshoot and noticeable oscillations. The temperature rises well above the specified setpoint before subsequently decreasing, and the stabilization process requires a longer time to settle. Such a tuning configuration may be hazardous for the reactor, since in a high-pressure, strongly exothermic autoclave process, excessive temperature excursions can adversely affect technological safety.

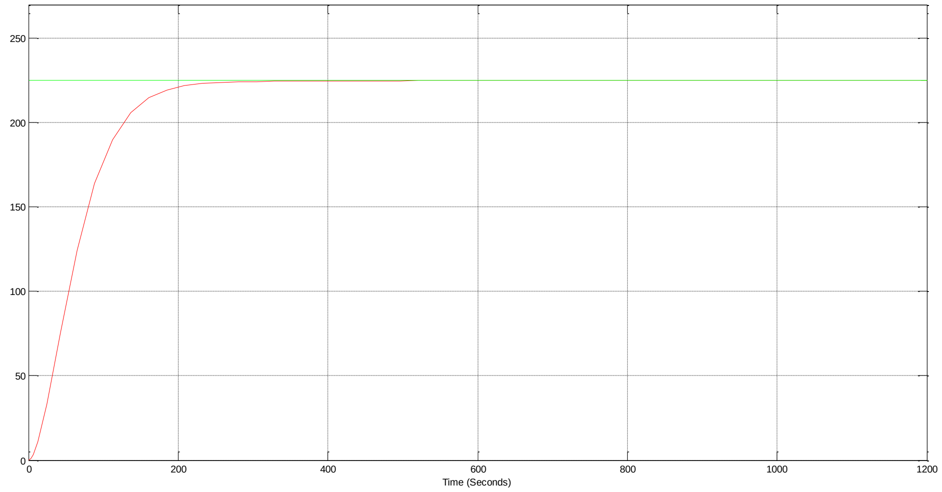

Figure 6. Transient response of the reactor temperature under aggressive PI controller settings (gain $K = 1.96$, integral time $Ti = 0.02267$)

In the graph presented in Figure 6, the PI controller parameters represent a tuning condition close to an optimal balance. Despite the relatively high proportional gain, the sufficiently increased integral time smooths the integral action of the controller. As a result, the reactor temperature approaches the desired setpoint rapidly, without oscillations and with negligible overshoot. As can be seen from the graph, the settling time is short and the steady-state error is practically zero. This behavior indicates that the selected PI controller parameters are well matched to the thermal inertia and dynamic characteristics of the reactor.

Conclusion.

In this study, the automatic temperature control system of a high-pressure autoclave reactor of the DC-2101 type used in Sclairtech technology was modeled based on a PI controller, and comprehensive simulation studies were carried out in the MATLAB/Simulink environment. The strongly exothermic nature of the ethylene homopolymerization process in the autoclave reactor, together with its large thermal capacity and slow dynamic response, demonstrates that accurate and stable temperature control represents a critical technological task.

The modeling and simulation results confirmed that the selection of PI controller parameters has a significant influence on the quality of the reactor temperature transient responses. In cases where a low proportional gain and a very short integral time were applied, the system remained stable; however, the process of reaching the desired operating temperature was relatively slow. As the proportional gain increased, the dynamic response of the system became faster, but in certain cases excessive overshoot and oscillations were observed, which are undesirable for high-pressure and potentially hazardous autoclave processes.

Analysis of the simulation graphs showed that a PI controller tuned with $K = 1.96$ and $T_{\text{i}} = 0.02267$ provides the most favorable balance for automatic reactor temperature control. Under these settings, the reactor temperature approaches the specified operating value of $225\ {}^{\circ}C$ rapidly, smoothly, without oscillations, and with negligible steady-state error. The control signal varies without abrupt changes, thereby limiting excessive loading of the cooling circuit and enhancing overall process safety.

Overall, the results of this study demonstrate that a PI controller represents a sufficiently effective and reliable solution for automatic temperature control in high-pressure autoclave reactors. The proposed mathematical model and PI controller tuning can contribute to maintaining stable reactor temperature conditions in Sclairtech technology, ensuring consistent product quality, and reducing the risk of emergency technological situations. The findings provide a solid scientific and practical basis for the design and industrial implementation of automatic control systems in real high-pressure reactor applications.

References:

1.Raximov B.A., To'xtayev S.M. Kimyo-texnologik jarayonlarni avtomatlashtirish asoslari. Toshkent: Fan va texnologiya, 2016.
2.Seborg, D. E., Edgar, T. F., Mellichamp, D. A., & Doyle, F. J.
Process Dynamics and Control. 3rd ed. Hoboken, NJ: John Wiley & Sons, 2011.
3.Ogunnaike B.A., Ray W.H. Process Dynamics, Modeling, and Control. New York: Oxford University Press, 1994.
4.Лукьянов С.В. Автоматическое регулирование температуры в автоклавных реакторах // Автоматика и телемеханика. — 2015. — №7. — С. 98–107.
5.Ismoilov J.X., Abdullayev S.S. Avtoklav reaktorlarda haroratni avtomatik boshqarish masalalari // Kimyo va kimyo texnologiyasi. — 2020. — №3. — B. 45–52.
6.Turman, E. & Strasser, W. (2022). CFD Modeling of LDPE Autoclave Reactor to Reduce Ethylene Decomposition. Chemical Engineering Science, 257, 117722.
7.Kadirov, Y.. Control of Reactor Temperature and Pressure using Cascade Controllers. E3S Web of Conferences. (2023)
8.Liu, Z. & Luan, X.. Intelligent Modeling for Batch Polymerization Reactors with Unknown Inputs. Sensors, 23(13), 6021. (2023)
9.РА Бабаяров, КИ Усманов, АА Жаббаров Исследование скорости естественной циркуляции раствора хлопкового масла в вертикальном выпарном аппарате Universum: технические науки Universum: технические науки, 65-68 https://scholar.google.com/citations?view_op=view_citation&hl=ru&user=Z5rGHcsAAAAJ&citation_for_view=Z5rGHcsAAAAJ:qjMakFHDy7sC
10.Etike, E., Özkan, G., & Hapoglu, H. Temperature Control in Polystyrene Polymerization Reactor by Using Neural Network Model Predictive Algorithm. J. Indian Chem. Soc., 97 (2020).
11.Tizzo, L. Improvements in Energy Efficiency of Polyethylene Autoclave Reactor Using Advanced Process Control. IFAC Proceedings. (2012).
12.Istomin A.L. (2023). Исследование устойчивости химического реактора полимеризации этилена.
13.Macromolecular Reaction Engineering, Wiley-VCH (2020 Impact Factor ~1.93)