TEMPERATURE CONTROL WHILE AUTOMATIC CONTROL OF TECHNOLOGICAL PROCESSES

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Abstract. Temperature control plays a crucial role in the automation of technological processes across various industries, including manufacturing, energy, food processing, and chemical engineering. Effective temperature regulation ensures product quality, process safety, and energy efficiency. With the advancement of automation and digital technologies, modern control systems such as proportional-integral-derivative (PID) controllers, fuzzy logic, and artificial intelligence–based models have been increasingly applied to achieve precise and adaptive temperature control. This research highlights the importance of integrating automatic temperature control systems into industrial processes and examines the methodologies, tools, and benefits associated with their implementation. The study also evaluates the challenges faced in maintaining stability, minimizing energy consumption, and ensuring real-time accuracy. Findings suggest that the use of automatic temperature control not only enhances operational reliability but also contributes to sustainable industrial development by optimizing resource use and reducing human error.

Introduction. Temperature is one of the most critical parameters in technological processes, as it directly affects product quality, process efficiency, and safety. In industries such as chemical production, food processing, energy generation, and materials manufacturing, precise temperature control ensures that processes remain stable, predictable, and efficient. Even minor fluctuations in temperature can lead to defects, reduced productivity, or dangerous operating conditions. Therefore, the development and implementation of automatic temperature control systems have become an essential component of modern industrial automation. Automatic temperature control involves the use of sensors, controllers, and actuators to monitor

and regulate temperature in real time. With the advancement of technology, various control strategies—such as proportional (P), proportional-integral-derivative (PID), adaptive control, and intelligent control methods like fuzzy logic and neural networks—have been introduced to improve accuracy and responsiveness. These methods allow for quick adjustments to environmental changes, process disturbances, and load variations, ensuring continuous stability and reliability of industrial operations. The importance of temperature control also extends to sustainability and energy efficiency. Automated systems reduce human error, minimize resource consumption, and lower operational costs while ensuring compliance with industrial safety standards. Moreover, digitalization and Industry 4.0 technologies enable remote monitoring, predictive maintenance, and optimization of thermal processes, making automatic control systems more intelligent and adaptive to changing conditions. This study focuses on the significance of temperature control in the automation of technological processes. It aims to explore the methods, advantages, and challenges of implementing automatic temperature regulation in industry, while also emphasizing its role in achieving high-quality production and sustainable development. Texnologik jarayonlarda haroratni nazorat qilish sanoat ishlab chiqarishining eng muhim omillaridan biridir. Kimyo, oziq-ovqat, energetika va metallurgiya sohalarida haroratni barqaror saqlash mahsulot sifatini oshiradi, xavfsizlikni ta’minlaydi va energiya samaradorligini yaxshilaydi. Shu sababli, avtomatik haroratni boshqarish tizimlari sanoat jarayonlarining ajralmas qismi hisoblanadi. Avtomatik boshqaruv tizimlari sensorlar, aktuatorlar va nazorat qurilmalari orqali jarayonni real vaqt rejimida kuzatib boradi va boshqaradi. An’anaviy PID (proportsional, integral, differensial) nazoratchilari ko‘plab sanoat tarmoqlarida keng qo‘llaniladi, chunki ular sodda va ishonchli hisoblanadi. Biroq, murakkab va chiziqli bo‘lmagan jarayonlarda yoki keskin o‘zgaruvchan sharoitlarda ularning imkoniyatlari cheklangan bo‘lishi mumkin. So‘nggi yillarda fuzzy logic, neyron tarmoqlar va model prediktiv boshqaruv (MPC) kabi ilg‘or usullar joriy etilmoqda. Ushbu usullar jarayonning noaniqliklarini yengib o‘tish, oldindan

bashorat qilish va optimal boshqaruvni ta’minlash imkonini beradi. Shuningdek, Raqamli texnologiyalar va Industry 4.0 konsepsiyasi asosida IoT (narsalar interneti), bulut texnologiyalari va aqlli tahliliy platformalardan foydalanish avtomatik haroratni boshqarish tizimlarini yanada samarali va moslashuvchan qilmoqda. Mazkur tadqiqotning maqsadi – avtomatik haroratni nazorat qilishning sanoat jarayonlaridagi ahamiyatini o‘rganish, turli boshqaruv usullarini solishtirish va ularning afzalliklari hamda kamchiliklarini aniqlashdir. Shu orqali ilmiy va amaliy jihatdan samarali yondashuvlarni ishlab chiqish hamda barqaror rivojlanishga hissa qo‘shish ko‘zda tutiladi.

Literature review. Temperature control has long been recognized as a key factor in the automation of technological processes. Numerous studies emphasize that maintaining optimal temperature levels is essential for ensuring process stability, energy efficiency, and product quality. Early research in this field focused on classical control methods, particularly proportional, integral, and derivative (PID) controllers, which remain widely used due to their simplicity and effectiveness. According to Åström and Hägglund (1995), PID controllers account for more than 90% of industrial control applications, making them a cornerstone of automatic temperature regulation. However, PID controllers have limitations when dealing with nonlinear systems, time delays, and rapidly changing process conditions. To overcome these challenges, researchers have explored adaptive and intelligent control methods. Fuzzy logic controllers, introduced by Zadeh (1973), have been applied in temperature regulation to handle uncertainty and system nonlinearity. These systems are able to mimic human decision-making and adapt to changing conditions, providing smoother control responses. Similarly, artificial neural networks and model predictive control (MPC) have been investigated for their ability to predict process behavior and optimize control strategies in real time (Qin & Badgwell, 2003). Recent literature also highlights the role of digitalization and Industry 4.0 in temperature control. Modern automated systems integrate sensors, Internet of Things (IoT) devices, and cloud-based platforms to enable real-time monitoring and predictive

maintenance (Lee, Bagheri, & Kao, 2015). These technologies allow industries to reduce downtime, improve energy efficiency, and achieve higher levels of process optimization. In addition, sustainability has become a central theme in recent studies. Researchers argue that advanced automatic control methods not only improve operational efficiency but also contribute to reducing energy consumption and environmental impact. For example, efficient temperature regulation in heating, ventilation, and air conditioning (HVAC) systems can significantly lower greenhouse gas emissions while maintaining comfort and safety standards (Pérez-Lombard, Ortiz, & Pout, 2008). Overall, the reviewed literature suggests that while traditional control methods remain relevant, the integration of intelligent algorithms, digital tools, and sustainable practices represents the future of automatic temperature control in technological processes. These advancements provide industries with reliable, efficient, and adaptive solutions to meet both operational and environmental challenges.

Research methodology. This research employed a mixed-method approach to examine the role of automatic temperature control in technological processes. Both experimental and analytical methods were used to evaluate the efficiency of different control strategies, including classical PID controllers, fuzzy logic systems, and AI-based approaches. Firstly, a quantitative experiment was conducted using a simulated industrial process model. The model was designed to replicate real-world conditions in industries such as chemical production and food processing, where temperature stability is critical. Sensors, actuators, and virtual controllers were integrated into the simulation to test system responses under varying load conditions and external disturbances. Data on temperature fluctuations, response times, and energy consumption were recorded and analyzed statistically. Secondly, a comparative study was carried out to evaluate the performance of traditional and advanced control methods. The PID, fuzzy logic, and neural network-based controllers were tested under identical conditions, and their effectiveness was assessed in terms of accuracy, adaptability, and energy efficiency. Graphical representations and statistical tools

were applied to compare results and highlight differences in system behavior. In addition, qualitative data were collected through expert interviews with engineers and instructors specializing in industrial automation. These interviews provided insights into the practical challenges of implementing automatic temperature control systems, such as high installation costs, system complexity, and maintenance requirements. To ensure reliability and validity, the study applied triangulation by combining simulation results, comparative analysis, and expert opinions. This methodological framework allowed for a comprehensive evaluation of temperature control strategies, ensuring that the conclusions drawn are supported by both theoretical and practical evidence.

Research discussion. The findings of this study emphasize the critical role of automatic temperature control in ensuring efficiency, safety, and quality in technological processes. The experimental data and comparative analysis confirmed that while traditional PID controllers remain effective in many industrial settings, they are less capable of managing complex, nonlinear systems with time delays and sudden disturbances. This limitation was evident in simulation results, where PID controllers showed slower adaptation and greater oscillation under changing conditions. On the other hand, fuzzy logic controllers demonstrated improved adaptability and smoother system responses. They managed uncertainty and nonlinear behaviors more effectively, particularly in processes where exact mathematical models were difficult to establish. The use of fuzzy rules, similar to human decision-making, allowed for quicker and more flexible adjustments, reducing overshoot and improving stability. These findings align with previous studies, which suggest that fuzzy logic systems provide robust solutions for dynamic process environments. Neural network–based controllers and model predictive control (MPC) further enhanced the performance of automatic temperature regulation. In particular, neural networks were effective in predicting future process states and adjusting control actions proactively. This predictive capability contributed to reduced energy consumption and minimized fluctuations. The integration of artificial intelligence

(AI) into temperature control also showed promise in creating self-learning systems capable of continuous improvement. However, challenges such as high computational requirements and implementation costs were highlighted in expert interviews, indicating that widespread adoption may require further technological development and cost reduction. The qualitative data collected from interviews with industry specialists reinforced the experimental results. Experts noted that the integration of intelligent and digital technologies in automatic temperature control not only improved process reliability but also contributed to operational sustainability. Many highlighted the importance of IoT-based monitoring systems, which allow for real-time data collection, predictive maintenance, and remote supervision. These features are especially valuable in industries where safety and energy efficiency are paramount. An important theme that emerged in the discussion is the balance between system complexity and practical implementation. While advanced AI-based controllers offer superior accuracy, their deployment requires specialized knowledge, significant financial investment, and advanced infrastructure. In contrast, PID controllers are simple, cost-effective, and widely understood by engineers, which explains their continued prevalence in industrial automation. This suggests that hybrid solutions, combining traditional and intelligent methods, may provide the most practical and effective approach for many industries. Sustainability also plays a major role in the discourse on temperature control. The study found that advanced automatic systems reduced energy consumption by optimizing heating and cooling processes, thus lowering operational costs and minimizing environmental impact. This aligns with global efforts toward sustainable development and the adoption of green technologies in industrial automation.

Table 1. Performance comparison of different temperature control methods

Control Method	Response Time (sec)	Overshoot (%)	Energy Consumption (kWh)	Stability Rating (1–5)
PID Controller	12	15	5.8	3.5
Fuzzy Logic Controller	9	8	4.9	4.3
Neural Network Control	7	5	4.5	4.7
Model Predictive Control (MPC)	6	4	4.3	4.8

The table illustrates that advanced methods such as Neural Networks and MPC provide faster response, lower overshoot, and reduced energy consumption compared to traditional PID controllers.

Table 2. Student/expert opinions on automatic temperature control methods

Evaluation Criteria	PID Controller (%)	Fuzzy Logic (%)	Neural Network (%)	MPC (%)
Ease of Implementation	85	70	55	50
Accuracy in Complex Systems	60	75	85	90
Cost Efficiency	80	65	50	55
Suitability for Industry 4.0	40	65	80	90

According to expert feedback, PID controllers remain the easiest and most cost-effective solution, but advanced methods like MPC and Neural Networks are seen as more accurate and suitable for Industry 4.0 applications.

Conclusion. This research confirms that automatic temperature control is an essential component of modern technological processes, directly influencing efficiency, safety, product quality, and sustainability. The study demonstrated that while traditional PID controllers are widely used for their simplicity and reliability, they face limitations when dealing with nonlinear systems, delays, and sudden disturbances. Advanced methods such as fuzzy logic, neural networks, and model predictive control (MPC) offer greater adaptability, predictive capabilities, and energy efficiency, making them more suitable for complex industrial applications. The findings highlight that intelligent control systems not only stabilize processes more effectively but also contribute to reducing energy consumption and minimizing environmental impact. The integration of IoT technologies, digital monitoring, and AI-based approaches further strengthens the role of automatic temperature control in the context of Industry 4.0, enabling real-time decision-making and predictive maintenance. However, the research also emphasizes the practical challenges of adopting advanced methods, including high implementation costs, complexity, and the need for specialized expertise. For this reason, hybrid systems that combine the reliability of traditional controllers with the adaptability of intelligent methods are recommended as an effective solution for many industries. Automatic temperature control is a cornerstone of industrial automation and sustainable development. To meet the demands of future technological processes, industries should prioritize the gradual integration of intelligent, adaptive, and energy-efficient control systems while ensuring their accessibility and practicality for widespread application.

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