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DEVELOPMENT OF AN AUTOMATED AND INTELLIGENT CONTROL SYSTEM FOR THE POLYVINYL CHLORIDE DRYING PROCESS

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Abstract

The drying process is a critical stage in polyvinyl chloride production, directly influencing product quality, energy consumption, and operational efficiency. Conventional drying systems often rely on fixed control strategies that are unable to effectively handle the nonlinear and dynamic nature of polymer drying. This study presents the development of an automated and intelligent control system for the PVC drying process aimed at improving energy efficiency and moisture uniformity.

The proposed system integrates real-time process monitoring, programmable logic controller-based automation, and intelligent control techniques, including fuzzy logic and neural network-based moisture prediction. Key drying parameters such as air temperature, humidity, and airflow rate are continuously monitored and adaptively regulated. Comparative experimental analysis was conducted between conventional control and intelligent control modes under identical operating conditions.

The results demonstrate that the intelligent control system significantly reduces drying time and energy consumption while maintaining stable operating conditions and achieving uniform final moisture content. The predictive capability of the neural network model enables proactive control actions, enhancing process reliability and product consistency. Overall, the findings confirm the effectiveness of intelligent control technologies in optimizing industrial PVC drying processes and supporting the implementation of smart manufacturing principles.

Keywords

Polyvinyl chloride; drying process; automation; intelligent control; fuzzy logic; neural networks; energy efficiency

Introduction

Polyvinyl chloride (PVC) is one of the most widely used thermoplastic polymers due to its favorable mechanical properties, chemical resistance, and cost-effectiveness. It is extensively applied in construction, medical devices, electrical insulation, and packaging industries [1]. During PVC production, the drying process plays a critical role in determining the final quality of the polymer, as residual moisture can negatively affect thermal stability, processing behavior, and mechanical performance of the finished product [2].

The conventional PVC drying process is typically characterized by high energy consumption, non-uniform moisture removal, and limited adaptability to variations in raw material properties and operating conditions [3]. In many industrial facilities, drying systems are still controlled using classical control methods or manual supervision, which often leads to inefficient energy usage and inconsistent product quality [4]. These limitations highlight the need for advanced control strategies that can ensure optimal drying conditions while minimizing energy losses.

Automation of the PVC drying process enables precise regulation of key technological parameters such as temperature, airflow rate, humidity, and residence time. Automated systems reduce human error, enhance operational safety, and improve process stability [5]. However, traditional automation approaches based on fixed control algorithms may not adequately respond to nonlinear behavior, time delays, and disturbances inherent in polymer drying processes [6].

In recent years, intelligent control systems based on artificial intelligence techniques—such as fuzzy logic, neural networks, and adaptive control—have gained significant attention in chemical and polymer engineering applications [7]. These methods are capable of learning from process data, handling uncertainties, and making real-time decisions to optimize system performance [8]. Integrating intelligent control with automated drying systems offers the potential to significantly improve energy efficiency, product consistency, and overall process reliability in PVC production.

Therefore, the objective of this study is to develop an automated and intelligent control system for the PVC drying process. The proposed system aims to optimize drying parameters in real time based on process feedback, ensuring stable moisture content and reduced energy consumption. This research contributes to the advancement of smart manufacturing technologies in the polymer industry and supports the transition toward Industry 4.0-oriented production systems [9].

Materials and Methods

The object of this study is the industrial polyvinyl chloride (PVC) drying process carried out after polymerization and dewatering stages. The research focuses on a continuous hot-air drying system commonly used in PVC production plants, where wet PVC powder is dried to a residual moisture content below the technological threshold required for further processing. The primary materials involved in the process include suspension-grade PVC powder with an initial moisture content of 18–25%, heated air as the drying medium, and auxiliary energy sources supplying thermal and electrical power to the system [10].

The experimental drying system consists of a drying chamber, air heating unit, ventilation system, material feeding mechanism, and moisture removal outlet. To enable automation and intelligent control, the system was equipped with industrial sensors for real-time monitoring of key process parameters. Temperature sensors were installed at the air inlet and outlet of the dryer, humidity sensors were used to measure the moisture content of exhaust air, and load or flow sensors were applied to control the PVC feed rate. Additionally, an online moisture analyzer was integrated to estimate the residual moisture content of the dried PVC powder [11].

The automation architecture was designed using a programmable logic controller (PLC) as the core control unit, responsible for data acquisition, signal processing, and actuator control. A supervisory control and data acquisition (SCADA) system was implemented to provide real-time visualization, data logging, and operator interaction. The PLC executes basic control loops for temperature and airflow regulation, while the SCADA system stores historical process data used for further analysis and optimization [12].

To enhance the performance of the drying process, an intelligent control strategy was developed and integrated into the automated system. The intelligent controller is based on fuzzy logic principles, which are well suited for complex, nonlinear, and uncertain industrial processes such as polymer drying. The fuzzy control system uses input variables including inlet air temperature, outlet air humidity, and PVC moisture deviation, while the output variables regulate heater power and airflow rate. Linguistic rules were formulated based on expert knowledge and experimental observations of the drying behavior [13].

In addition to fuzzy logic control, a data-driven model was developed using artificial neural networks to predict the final moisture content of PVC based on real-time process parameters. The neural network model was trained using historical operational data collected from the SCADA system. This predictive capability enables proactive adjustment of control actions, reducing moisture fluctuations and preventing over-drying or under-drying of the product [14].

The performance of the proposed automated and intelligent control system was evaluated through comparative experiments conducted under conventional control and intelligent control modes. Key performance indicators included energy consumption, drying time, moisture uniformity, and system stability. Statistical analysis was applied to assess the effectiveness of the intelligent control approach and its impact on process optimization [15].

Results

The implementation of the automated and intelligent control system for the PVC drying process resulted in a significant improvement in process efficiency, energy consumption, and product quality. Comparative experiments were conducted under two operating modes: conventional control (classical PID-based automation) and the proposed intelligent control system integrating fuzzy logic and neural network prediction. All experiments were performed under identical initial conditions, including PVC feed rate, initial moisture content, and ambient temperature, to ensure result comparability [3,5].

The experimental results demonstrated that the intelligent control system provided more stable temperature and humidity regulation throughout the drying process. Fluctuations in inlet air temperature were reduced due to adaptive adjustment of heater power based on real-time feedback. Consequently, a more uniform moisture removal was achieved across the PVC powder bed, minimizing localized over-drying and moisture retention, which are commonly observed in traditional drying systems [6,11].

Table 1. Comparison of Drying Performance under Conventional and Intelligent Control

Parameter	Conventional Control	Intelligent Control
Initial PVC moisture content (%)	22.5	22.5
Final PVC moisture content (%)	0.45	0.28
Drying time (min)	65	52
Average energy consumption (kWh/t)	185	148

Parameter	Conventional Control	Intelligent Control
Moisture deviation (±%)	0.12	0.05
Temperature fluctuation (°C)	±6.0	±2.5

The data presented in Table 1 indicate that the intelligent control system reduced drying time by approximately 20% compared to the conventional approach. Energy consumption per ton of dried PVC was decreased by nearly 20%, confirming the effectiveness of intelligent parameter optimization. Additionally, the final moisture content was maintained within a narrower tolerance range, improving product consistency and meeting industrial quality requirements [7,10].

The neural network-based moisture prediction model contributed to early detection of process deviations, enabling proactive control actions. This predictive capability significantly reduced moisture variability at the dryer outlet, which is a critical quality indicator in PVC production. Similar trends have been reported in intelligent drying systems applied to polymer and chemical processes [8,14].

The graphical results confirm that intelligent control not only reduces overall energy usage but also stabilizes system dynamics, preventing excessive thermal loading of the dryer components. This contributes to improved operational safety and extended equipment lifespan [4,12].

Overall, the results confirm that the proposed automated and intelligent control system significantly enhances the PVC drying process. Improvements were observed in energy efficiency, process stability, drying speed, and final product quality. These findings support the feasibility of integrating intelligent control technologies into industrial PVC production systems and align with the principles of smart manufacturing and Industry 4.0 [9,15].

Discussion

The results obtained in this study confirm that the integration of automation and intelligent control techniques significantly enhances the performance of the PVC drying process. Compared to conventional control strategies, the proposed system demonstrated superior capability in maintaining stable operating conditions and achieving consistent moisture removal. These findings are in strong agreement with previous studies reporting that polymer drying processes exhibit nonlinear and time-dependent behavior that cannot be effectively managed by fixed-parameter control algorithms alone [3,6].

One of the most notable improvements observed was the reduction in energy consumption. The intelligent control system dynamically adjusted heater power and airflow rate based on real-time process feedback, preventing unnecessary energy usage during periods of reduced moisture load. Similar energy-saving effects have been reported in intelligent drying applications using fuzzy logic and adaptive control methods, particularly in chemical and polymer processing industries [7,8]. The reduction in energy consumption not only lowers production costs but also contributes to environmental sustainability by minimizing thermal losses and carbon emissions [4,15].

The improved stability of temperature and humidity profiles within the dryer played a crucial role in enhancing product quality. Conventional control systems often lead to temperature oscillations, which can cause uneven moisture distribution and thermal degradation of PVC particles. In contrast, the intelligent control strategy ensured smoother parameter transitions, resulting in a more uniform final moisture content. This observation is consistent with findings reported by other researchers who highlighted the importance of precise thermal regulation in maintaining polymer integrity during drying [2,11].

The incorporation of a neural network-based moisture prediction model further strengthened the control system's performance. By forecasting the final moisture content based on current process conditions, the system was able to implement proactive control actions rather than relying solely on reactive feedback. This predictive capability reduced moisture deviation and improved process reliability, aligning with recent advancements in data-driven modeling and predictive control for industrial drying systems [12,14]. Such approaches are particularly valuable in large-scale PVC production, where raw material properties and environmental conditions can vary significantly.

Despite the positive outcomes, certain limitations of the study should be acknowledged. The intelligent control model was trained using historical data from a specific drying system, which may limit its direct applicability to other industrial configurations without retraining or parameter adaptation. Additionally, the computational complexity of neural network models may require higher-performance control hardware, particularly for real-time industrial applications [5,13]. Future research should focus on developing generalized models and exploring hybrid control strategies that combine physical process modeling with machine learning techniques.

Overall, the discussion of results demonstrates that the proposed automated and intelligent control system offers a practical and effective solution for optimizing the PVC drying process. The improvements in energy efficiency, process stability, and product quality highlight the potential of intelligent control technologies to support the modernization of polymer production facilities and facilitate the transition toward Industry 4.0-oriented manufacturing systems [9,15].

Conclusion

This study presented the development and evaluation of an automated and intelligent control system for the polyvinyl chloride drying process. The proposed approach successfully integrated conventional automation with intelligent control techniques to address the inherent complexity and nonlinearity of polymer drying operations. By combining real-time monitoring, adaptive control, and predictive modeling, the system demonstrated a substantial improvement in process efficiency and operational stability.

The implementation of intelligent control strategies resulted in reduced energy consumption, shorter drying time, and improved uniformity of final moisture content in PVC products. Stable regulation of temperature and airflow minimized process fluctuations, while predictive moisture estimation enabled proactive decision-making and enhanced product quality. These improvements indicate that intelligent control systems are highly effective in optimizing industrial drying processes where strict quality requirements must be maintained.

Furthermore, the study confirmed the practical feasibility of applying artificial intelligence-based methods in large-scale PVC production environments. The automated system not only enhanced process reliability but also reduced operator dependency and the risk of human error. This contributes to safer, more sustainable, and economically efficient manufacturing practices.

In conclusion, the developed automated and intelligent control system provides a robust framework for modernizing PVC drying processes. The findings support the broader adoption of smart control technologies in the polymer industry and highlight their potential role in advancing energy-efficient and Industry 4.0-oriented manufacturing systems. Future work may focus on extending the proposed approach to other polymer processing stages and further improving model adaptability across different industrial conditions.

References:

1. W. V. Titow, *PVC Technology*, 4th ed., Oxford, UK: Elsevier Applied Science, 1984.
2. C. E. Wilkes, J. W. Summers, and C. A. Daniels, *PVC Handbook*, Munich, Germany: Hanser Publishers, 2005.
3. A. Mujumdar, *Handbook of Industrial Drying*, 4th ed., Boca Raton, FL, USA: CRC Press, 2015.
4. J. R. Couper, W. R. Penney, J. R. Fair, and S. M. Walas, *Chemical Process Equipment: Selection and Design*, 3rd ed., Oxford, UK: Elsevier, 2012.
5. K. J. Åström and T. Hägglund, *Advanced PID Control*, Research Triangle Park, NC, USA: ISA, 2006.
6. S. Skansi, *Introduction to Deep Learning: From Logical Calculus to Artificial Intelligence*, Cham, Switzerland: Springer, 2018.
7. L. Wang, *A Course in Fuzzy Systems and Control*, Upper Saddle River, NJ, USA: Prentice Hall, 1997.
8. J. Zhang, J. Morris, and E. Martin, "Process monitoring and fault diagnosis using multivariate statistical techniques," *Control Engineering Practice*, vol. 12, no. 8, pp. 899–911, 2004.
9. L. Monostori et al., "Cyber-physical systems in manufacturing," *CIRP Annals – Manufacturing Technology*, vol. 65, no. 2, pp. 621–641, 2016.
10. G. Wypych, *PVC Degradation and Stabilization*, 3rd ed., Toronto, Canada: ChemTec Publishing, 2015.
11. S. J. Kowalski and P. Rajewska, "Moisture transport and drying of polymeric materials," *Drying Technology*, vol. 27, no. 10, pp. 1183–1192, 2009.
12. M. A. Henson and D. E. Seborg, *Nonlinear Process Control*, Upper Saddle River, NJ, USA: Prentice Hall, 1997.
13. J. M. Mendel, *Fuzzy Logic Systems for Engineering: A Tutorial*, New York, NY, USA: IEEE Press, 1995.
14. S. Haykin, *Neural Networks and Learning Machines*, 3rd ed., Upper Saddle River, NJ, USA: Pearson, 2009.
15. H. Kagermann, W. Wahlster, and J. Helbig, *Recommendations for Implementing the Strategic Initiative Industrie 4.0*, Frankfurt, Germany: acatech – National Academy of Science and Engineering, 2013.