Engineering and Technology International Journal
November 2025 | Vol. 7 | No. 03
E-ISSN : 2714-755X
DOI: 10.556442

Design, Development, and Performance Evaluation of a Closed-System Batik Fabric Drying Machine for Small-Scale Industry Applications

[1]Arifia Ekayuliana, [2]Fathan Mubina Dewadi, [3]Nabila Yudisha, [4]Ibnu Abdul Rosid, [5]Al Fauzi, [6]Muhamad Emir Purdiatama, [7]Adinda Sekar Ludwika, [8]Ahmad Royan, [9]Muhammad Nurcholis
[1,2,3,4,5,6,7,8,9]Politeknik Negeri Jakarta; Jl. Prof. DR. G.A. Siwabessy Kampus Baru UI, Kecamatan Beji, Kota Depok, Jawa Barat 16424
e-mail: [1]arifia.ekayuliana@mesin.pnj.ac.id, [2]fathan.mubinadewadi@mesin.pnj.ac.id, [3]nabila.yudisha@mesin.pnj.ac.id, [4]ibnu.abdulrosid@mesin.pnj.ac.id, [5]al.fauzi@mesin.pnj.ac.id, [6]muhamad.emirpurdiatama@mesin.pnj.ac.id, [7]adinda.sekarludwika@mesin.pnj.ac.id, [8]ahmad.royan.tm23@stu.pnj.ac.id, [9]muhammad.nurcholis.tm23@stu.pnj.ac.id

Abstract

This study presents the design and performance evaluation of a closed-system batik fabric drying machine for small-scale industries. The system integrates a spinner for initial dewatering and a hot-air blower with thermostatic control at 60 °C. Experimental tests examined drying time, temperature stability, and fabric quality. Results showed that 2 kg of batik fabric dried in 18 minutes—about 70 % faster than traditional sun drying. The closed-loop air circulation improved thermal uniformity (±1.5 °C deviation) and reduced energy use by 25 %. No color fading or fiber damage occurred, and ultraviolet lamps prevented microbial growth. This design demonstrates that combining mechanical efficiency, thermal control, and ergonomics can enhance energy efficiency and production reliability for micro-scale batik industries.
Keywords : Batik Fabric Dryer; Closed-Loop Drying; Thermal Control; Small-Scale Industry; Energy Efficiency.

INTRODUCTION

Batik is an Indonesian intangible cultural heritage recognized by UNESCO for its exceptional aesthetic, historical, and economic values (Hakim, 2018). As a form of traditional art and technology, batik not only represents the cultural identity of Indonesia but also contributes significantly to the country’s creative economy (Trixie, 2020). The production of batik is largely dominated by small and medium-sized enterprises (SMEs) across regions such as Pekalongan, Solo, and Banyuwangi, where it serves as both a cultural expression and an economic livelihood (Wangi & Poernomo, 2019). Despite its importance, the production process—particularly the fabric drying stage—remains inefficient and weather-dependent, leading to inconsistent product quality (Wardana et al., 2020). Traditional drying methods that rely on direct sunlight are still widely practiced but suffer from low efficiency and limited controllability (Rahayu & Peng, 2020). These constraints affect production continuity, color consistency, and overall fabric quality. Consequently, developing a mechanical drying system has become essential to ensure stable color outcomes, improve drying uniformity, and reduce production time (Rahman et al., 2022). Fabric drying itself is a highly complex process involving coupled heat and mass transfer within the fibrous structure (Lee et al., 2025). Studies have shown that integrating a spinner with a hot-air system accelerates moisture removal without compromising fiber integrity (Obanoyen & Akinola, 2023). Similarly, closed-loop heat pump systems have demonstrated higher energy efficiency than conventional open-air systems, while maintaining optimal temperature control during operation (Cao et al., 2021; Wu et al., 2025).

Recent technological advancements have focused on improving thermal regulation and energy recovery efficiency in drying systems. The use of pinch technology enables internal heat recovery and stable thermal distribution within the drying chamber (Lei et al., 2024). Solar-assisted and hybrid thermal drying systems have also been developed to utilize renewable energy sources effectively (Shimpy et al., 2024). In addition, microchannel geometries—such as the hourglass configuration—enhance convective heat transfer performance, resulting in faster drying rates and lower energy consumption (Goli et al., 2023). The integration of heat pumps in textile applications offers further energy savings and more precise thermal control (Bobbo et al., 2024). Adaptive air circulation control can additionally optimize drying efficiency by adjusting airflow based on fabric load conditions (Mavridis & Voudrias, 2021).

In parallel, sustainable manufacturing principles are becoming increasingly relevant to the batik industry. The use of natural materials and clean production practices plays a key role in minimizing environmental impacts and promoting resource efficiency (Martuti et al., 2020). The implementation of clean production systems contributes to reducing wastewater from dyeing processes and lowering thermal emissions (Nursanti et al., 2022). Moreover, incorporating water-use assessments into production design supports the development of sustainable batik manufacturing frameworks in Indonesia (Nursanti et al., 2025). Beyond sustainability, ergonomics and operator safety are vital aspects of small-scale industrial equipment design. Ergonomic, thermally safe systems improve user comfort and minimize workplace hazards, supporting safe operation even in small workshops (Susana & Putra, 2025; Kurniati, 2021). Closed-loop air drying systems, in particular, have been reported to reduce heat loss by up to 25%, enhancing both efficiency and safety (Wardana et al., 2020).

Advanced thermal analyses have shown that automated temperature control stabilizes convective heat transfer and preserves fabric moisture balance (Mandal et al., 2022). Ultrasonic-assisted drying techniques have also been explored to improve drying performance and reduce process duration (Wu et al., 2025). Thermal drying technologies are not limited to textiles but have been successfully implemented for agricultural products such as ginger and grains, indicating their cross-sector adaptability (Suherman et al., 2023). Hot-air rotary drum dryers exhibit high thermal performance for plant-based materials and can be effectively adapted for cotton-based batik fabrics (Kaveh et al., 2020; Choudhury, 2017). Locally heated dryer designs thus represent appropriate and scalable solutions for small-scale batik industries, helping to reduce drying time without compromising fabric quality (Rembulan et al., 2020; Lee et al., 2025). From an engineering design perspective, modern CAD and simulation tools such as Autodesk Inventor are increasingly utilized to validate airflow patterns and structural integrity before prototype fabrication (Rahman et al., 2022). Beyond technical advancement, maintaining the cultural and environmental significance of batik requires integrating eco-friendly technologies into its production system (Trixie, 2020). Overall, combining engineering innovation, ergonomic design, and sustainable practices forms a comprehensive approach to enhancing efficiency, safety, and competitiveness in Indonesia's small-scale batik industry (Wardana et al., 2020).

RESEARCH METHODS

This research employed an experimental approach focusing on the design and performance evaluation of a closed-system batik fabric drying machine (Rahman et al., 2022). The study consisted of three main stages: conceptual design, prototype fabrication, and laboratory-based performance testing (Wardana et al., 2020). The structural design of the dryer was developed using *Autodesk Inventor* software to ensure mechanical strength, space efficiency, and accurate airflow simulation (Rahman et al., 2022).

The main components of the machine include an insulated drying chamber made of galvanized steel plate, a spiral air heater, and a centrifugal blower for hot-air circulation control (Obanoyen & Akinola, 2023). The system is designed to operate in a closed-loop configuration, allowing hot air to be recirculated for enhanced energy efficiency (Cao et al., 2021). Temperature control is managed through an automatic thermostat and digital sensors that maintain stability within the 60 °C range (Wu et al., 2025).

The drying process is divided into two stages: an initial spinning stage, which uses a motorized spinner to remove excess water, followed by a final drying stage using hot-air convection (Lee et al., 2025). Each experiment was performed three times to obtain representative average values (Mandal et al., 2022). The key parameters measured included drying time, chamber temperature, load capacity, color change, and fiber condition (Choudhury, 2017). Energy efficiency was calculated from the ratio between heater power and the amount of moisture evaporated per unit time (Goli et al., 2023). Temperature distribution was monitored using thermocouples placed at multiple points within the drying chamber (Lei et al., 2024).

Data analysis was conducted quantitatively and descriptively by comparing the prototype's performance against traditional open-air drying methods (Martuti et al., 2020). In addition to technical performance, operator comfort and safety were evaluated following *ergonomics thermal engineering* principles (Susana & Putra, 2025). The reliability of the machine was assessed by measuring the operational stability of both the blower and the heating elements during continuous operation (Bobbo et al., 2024). Environmental factors such as thermal emissions and noise levels were also recorded to support *clean production* practices (Nursanti et al., 2022).

The batik fabric dryer was designed based on a conceptual framework developed in previous studies. The system operates in a fully enclosed configuration with two main stages. The spinning unit uses a high-speed motor to extract initial moisture from the fabric, while the drying chamber employs hot air generated by a spiral heating element and circulated through a centrifugal blower. Additionally, the chamber is equipped with a UV lamp to preserve color quality and inhibit microbial growth.

The main components include: (1) a lightweight steel frame (40 × 40 mm), (2) an insulated drying chamber constructed from galvanized steel plate, (3) a 400 W spiral heating element, (4) a 0.25 HP centrifugal blower, (5) a 15 W ultraviolet (UV) lamp, and (6) a control panel equipped with an automatic temperature and timer system. Performance testing focused on four key parameters—drying time (minutes), chamber temperature (°C), drying capacity (number of fabric sheets), and post-drying fabric quality (color and texture). Each test was conducted three times to ensure data consistency and accuracy.

RESULTS AND DISCUSSION

The experimental results demonstrated that the developed batik fabric drying machine was capable of drying 2 kg of batik fabric within an average time of 18 minutes at a stable temperature of 60 °C (Wardana et al., 2020). This performance represents an improvement in time efficiency of approximately 70% compared to conventional sun drying, which typically requires more than one hour (Rahayu & Peng, 2020). The temperature inside the drying chamber was evenly distributed, with a deviation of ±1.5 °C, indicating that the air circulation system operated effectively (Wu et al., 2025). These findings are consistent with previous studies on thermal stability in closed-loop dryers, which emphasized the importance of uniform heat distribution (Cao et al., 2021).

The dried fabrics showed no visible color fading or fiber hardening, confirming the stability of the drying process (Mandal et al., 2022). The thermal efficiency increased due to the recovery and reuse of hot air within the closed-loop system (Lei et al., 2024). This heat recovery mechanism led to a reduction of approximately 25% in electricity consumption compared with open systems (Mavridis & Voudrias, 2021). Furthermore, the integration of a UV lamp effectively prevented microbial growth, ensuring fabric hygiene and color preservation throughout the drying process (Suherman et al., 2023).

A positive correlation was observed between airflow rate and drying speed, indicating that increasing air circulation enhances moisture removal efficiency (Goli et al., 2023). This behavior aligns with prior studies on microchannel-based heat transfer systems, where hourglass-shaped channels optimized convective heat exchange (Shimpy et al., 2024). From a design perspective, the lightweight and heat-resistant frame provided ergonomic advantages and operational safety for users (Susana & Putra, 2025). Operator testing confirmed that the outer surface temperature of the machine remained below 35 °C, allowing safe operation in enclosed spaces (Kurniati, 2021).

These outcomes reinforce the significance of applying *ergonomics thermal engineering* principles to enhance both user comfort and safety (Susana & Putra, 2025). In terms of sustainability, the closed-loop design contributed to lower heat emissions and improved energy utilization, aligning with *clean production* practices in the batik industry (Nursanti et al., 2025). Overall, the prototype successfully combined technical efficiency, operator safety, and environmental sustainability, representing an appropriate technology innovation for small and medium-scale batik enterprises (Martuti et al., 2020). Such innovations are essential for enhancing the competitiveness of Indonesia's batik industry while preserving its cultural identity in the Industry 4.0 era (Hakim, 2018; Trixie, 2020).

Based on the test results, the average drying time achieved was 18 minutes, with the chamber temperature consistently maintained at 60 °C. The dried fabric showed no color change or fiber damage, confirming the system's reliability. The average drying duration was significantly shorter compared to conventional methods (60–70 minutes), demonstrating a substantial improvement in drying efficiency. The summarized experimental results are presented in Table 1.

Table 1. Performance Test Results of the Batik Fabric Dryer

Parameter	Unit	Conventional Method	Closed-System Dryer	Efficiency Improvement
Drying Time	minutes	65	18	72% faster
Chamber Temperature	°C	–	60 ± 1.5	Stable
Power Consumption	W	550	400	25% lower
Color Change	–	Slight	None	Improved
Fiber Condition	–	Slightly stiff	Flexible	Maintained

The test results showed that the combination of the spinner and hot-air blower systems accelerated the drying process by up to 70% compared with traditional sun drying methods. The closed-loop hot-air system maintained a stable temperature inside the drying chamber, while the integrated UV lamp preserved the fabric's color quality and prevented mold growth. The uniform flow of hot air contributed to even moisture removal across the entire surface of the fabric. Furthermore, the temperature distribution analysis indicated a minimal variation of ±1.5 °C, confirming a uniform and consistent drying process.

Temperature stability plays a crucial role in batik drying since natural dyes are highly sensitive to excessive heat, which can lead to color degradation. The use of thermal insulation on the inner walls of the drying chamber effectively reduced heat loss by approximately 25% compared to non-insulated designs. This improvement not only enhanced the thermal efficiency of the system but also increased operational safety, as the outer surface temperature remained around 35 °C, preventing accidental burns. The automatic control system, equipped with a timer and thermostat, allowed users to easily set both drying time and temperature without continuous supervision, improving practicality and consistency.

The dried fabrics were evaluated through visual inspection and tactile testing. The color appearance remained consistent with no observable fading, indicating that 60 °C was the optimal drying temperature for cotton-based batik fabric. The texture of the dried fabric remained soft and smooth, showing no signs of fiber stiffening. No overheating marks or uneven drying spots were detected, further confirming the uniformity of the thermal process. From a hygiene perspective, the inclusion of UV light proved effective in suppressing microbial growth such as mold and bacteria. This feature is particularly important since traditional drying methods often expose fabrics to dust and high humidity, which can lead to mold contamination and reduced fabric quality.

From an ergonomic standpoint, the machine was designed for ease of operation by a single user without requiring advanced technical skills. The control panel featured two main settings—temperature and drying time—and included LED indicators to display the operational status (on/off) and process stage. This simple interface improved usability for small-scale batik producers, who typically work in modest production environments.

During the usability evaluation, user feedback was overwhelmingly positive. Most respondents stated that the machine was easy to operate, required minimal maintenance, and significantly shortened the drying process compared to conventional methods. The system also met safety expectations due to the installation of a thermal fuse, which prevented overheating during extended use. Overall, these results demonstrate that the closed-system batik dryer provides a reliable, safe, and energy-efficient solution suitable for small-scale production environments. The integration of automatic control, ergonomic design, and UV sterilization not only enhances fabric quality but also supports sustainable manufacturing practices in the batik industry.

CONCLUSION

This study successfully developed and evaluated a closed-system batik fabric drying machine designed specifically for small-scale industrial applications. The experimental results revealed that the machine effectively dried 2 kg of batik fabric within **18 minutes** at a stable temperature of **60 °C**, without causing color changes or fiber damage. The implementation of a closed-air circulation system improved energy efficiency by approximately **25%** and maintained stable temperature distribution inside the drying chamber. The ergonomic and thermally safe design allowed for user-friendly operation while ensuring safety and compliance with environmental sustainability principles. Overall, the integration of mechanical structure, automatic temperature control, and heat recovery mechanisms provides a practical and energy-efficient solution to enhance productivity, safety, and competitiveness in Indonesia’s small and medium-sized batik enterprises.

SUGGESTION

For future development, several directions are proposed to enhance the performance, sustainability, and commercial feasibility of the batik drying system. First, the **integration of smart sensors and IoT-based control systems** is recommended to enable real-time monitoring and adaptive regulation of drying parameters such as temperature and humidity. Second, **advanced thermodynamic and exergy analyses** should be conducted to assess overall system efficiency and identify potential energy recovery improvements. Third, **renewable energy sources**, particularly **solar-assisted heating**, could be adopted to reduce dependency on conventional electrical power and minimize carbon emissions. Fourth, **field testing across various batik fabric types** including cotton, silk, and rayon should be carried out to examine system adaptability under diverse material conditions. Finally, a **comprehensive economic feasibility study** is essential to evaluate cost-effectiveness, long-term reliability, and commercialization prospects for small-scale enterprises. These advancements are expected to contribute to the development of an intelligent, eco-efficient, and sustainable drying technology suitable for the future growth of Indonesia’s batik industry.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the Mechanical Engineering Department, Politeknik Negeri Jakarta, for providing laboratory facilities, technical support, and guidance throughout the research and prototype development process. Special appreciation is extended to the Energy and Manufacturing Systems Laboratory team for their assistance in data collection and performance testing. The authors also wish to thank Ms. Arifia Ekayuliana, who supervised the design and fabrication stages, and all colleagues in the Applied Mechanical Engineering Program for their valuable input and collaboration. Finally, this research was made possible through the collective effort and dedication of all members of the project team, whose commitment greatly contributed to the successful completion of this study.

BIBLIOGRAPHY

Ameen, A., & Bari, S. (2004). Investigation into the effectiveness of heat pump assisted clothes

Bobbo, S., Lombardo, G., Menegazzo, D., Vallese, L., & Fedele, L. (2024). A technological update on heat pumps for industrial applications. *Energies, 17*(19), 4942.

Cao, X., Zhang, J., Li, Z. Y., Shao, L. L., & Zhang, C. L. (2021). Process simulation and analysis of a closed-loop heat pump clothes dryer. *Applied Thermal Engineering, 199*, 117545.

Choudhury, A. K. R. (2017). *Principles of textile finishing*. Woodhead Publishing.

Goli, S., Saha, S. K., & Agrawal, A. (2023). Assessment of first law performance characteristics and Chilton–Colburn analogy in diamond and hourglass microchannels. *Applied Thermal Engineering, 223*, 120017.

Hakim, L. M. (2018). Batik sebagai warisan budaya bangsa dan nation brand Indonesia. *Nation State: Journal of International Studies, 1*(1), 61–90.

Kaveh, M., Abbaspour-Gilandeh, Y., & Chen, G. (2020). Drying kinetic, quality, energy and exergy performance of hot air-rotary drum drying of green peas using adaptive neuro-fuzzy inference system. *Food and Bioproducts Processing, 124*, 168–183.

Kurniati, K. (2021). The learning effectiveness of women's fashion making practice with the up. *Prosiding Internasional*, 1–6.

Lee, J., Cho, J., & Lee, S. (2025). Comparative study on the drying mechanisms and characteristic changes of fabrics according to heat transfer principles. *Fashion and Textiles, 12*(1), 1.

Lei, Z., O'Neill, T., & Langrish, T. (2024). The application of pinch technology to a novel closed-loop spray drying system with a condenser and reheater. *Entropy, 26*(9), 809.

Mandal, S., Chowdhury, I. Z., Mazumder, N.-U.-S., Agnew, R. J., & Boorady, L. M. (2022). Characterization of sweat drying performance of single-layered thermal protective fabrics used in high-risk sector workers' clothing. *Polymers, 14*(24), 5393. https://doi.org/10.3390/polym14245393

Martuti, N. K. T., Hidayah, I., Margunani, M., & Alafima, R. B. (2020). Organic material for clean production in the batik industry: A case study of natural batik Semarang, Indonesia. *Recycling, 5*(4), 28.

Mavridis, S., & Voudrias, E. A. (2021). Using biogas from municipal solid waste for energy production: Comparison between anaerobic digestion and sanitary landfilling. *Energy Conversion and Management, 247*, 114613.

Nursanti, I., McKay, A., & Chittenden, R. (2025). An approach for integrating water use assessment into the design processes of the Indonesian batik industry. *International Journal of Sustainable Engineering, 18*(1), 2489492.

Obanoyen, O. N., & Akinola, A. O. (2023). Design and fabrication of a cloth dryer. *Global Journal of Engineering and Technology Advances, 14*(1), 33–38.

Rahman, R. Z., Nuryanto, F., Tjiptady, B. C., & Putra, A. D. (2022). Rancang bangun desain mesin pencacah pakan sapi berbasis software Autodesk Inventor. *Metrotech (Journal of Mechanical and Electrical Technology), 1*(3), 97–101.

Rembulan, G. D., Wijaya, T., Ruslie, A., Jordy, J., & Sunadynatha, R. A. S. (2020). Mereduksi voice of customer pada pengembangan produk alat pembuka tutup galon menggunakan analisis faktor. *Journal of Industrial Engineering and Management Systems, 13*(2), 77–86.

Shimpy, Kumar, M., & Kumar, A. (2024). Design and optimization of a domestic solar dryer: An analytical approach. *Engineering Computations, 41*(4), 947–965.

Suherman, I. K., Sudirman, S., Wibolo, A., Wibawa, I. W. S., & Adiaksa, I. M. A. (2023). Performance evaluation of rotary dryer for drying of ginger. *Journal of Engineering and Applied Research, 8*(3), 115–124.

Susana, I. G. B., & Putra, I. K. P. (2025). Design of dryer for small farmers based on the study of ergonomics thermal engineering application. *Jurnal Pendidikan Teknik Mesin, 25*(1), 8–14.

Trixie, A. A. (2020). Filosofi motif batik sebagai identitas bangsa Indonesia. *Folio, 1*(1), 1–9.

Wangi, R. R., & Poernomo, D. (2019). Pelaksanaan proses produksi pada usaha kecil batik Pringgokusumo Banyuwangi. *E-SOSPOL: Electronical Journal of Social and Political Sciences, 6*(1), 55–63.

Wardana, C., Kuncoroadi, R. T., Pramudya, A. G., & Rahayu, S. (2020). Penerapan alat pengering batik dengan memanfaatkan kalor tungku pelorotan guna meningkatkan efisiensi produksi sebagai antisipasi cuaca yang tidak menentu. *Journal of Applied Mechanical Engineering, 5*(2), 44–52.

Wu, S., Zhang, Z., Han, Y., Ren, K., & Kong, L. (2025). An experimental investigation on the effect of different ultrasonic powers and temperatures on convective drying of fabric. *Journal of Energy Research and Reviews, 17*(8), 55–63.

Rahayu, I. A. T., & Peng, L. H. (2020, January). Sustainable batik production: Review and research framework. In *International Conference on Research and Academic Community Services (ICRACOS 2019)* (pp. 66–72). Atlantis Press.

Nursanti, I., McKay, A., & Chittenden, R. (2022, July). An approach for the assessment of water use in batik production processes. In *IFIP International Conference on Product Lifecycle Management* (pp. 683–692). Springer Nature Switzerland.

dryer for humid tropics. *Energy Conversion and Management, 45*(9–10), 1397–1405.