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Waste Reduction in the Mosquito Coil Drying Process

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Abstract

Productivity is a key factor in achieving competitive advantage; therefore, industrial manufacturers must continuously reduce operational costs. In mosquito coil production, steam boilers are essential for the drying process, which typically requires 8–9 hours per batch and results in high energy consumption. The case study factory encountered several problems, including insufficient steam supply, uneven heat distribution in the drying chamber, and prolonged drying time. These issues increased production costs and caused defects such as deformation, breakage, and structural damage. This study aimed to evaluate the performance of the steam boiler and drying system in order to improve production efficiency and reduce defects. Pareto Diagram analysis was employed to identify major defect types, while Why-Why Analysis was used to determine root causes. The results indicated that product deformation was the most significant defect. The main cause was insufficient steam supply resulting from scale accumulation inside the boiler due to poor feedwater quality, which reduced heat transfer efficiency. System improvements were implemented, focusing on upgrading the steam supply control system with an investment cost of 150,000 THB. Consequently, drying time was reduced by 1–2 hours (16.09%), defect rates decreased by 8.55%, and drying costs were reduced by 32,826.82 THB.

Keywords
Steam Boiler, Drying Chamber, Process Improvement, Waste Reduction, Systems Engineering

1. Introduction

Vector-borne diseases remain a significant public health challenge, particularly in tropical and subtropical regions where climatic conditions favor the growth and reproduction of insects such as mosquitoes (World Health Organization, 2023). Thailand continues to experience persistent outbreaks of mosquito-borne diseases, especially dengue fever, which poses serious health and economic impacts on society. According to the Department of Disease Control, Ministry of Public Health of Thailand, more than 105,000 dengue cases were reported nationwide in 2024, with a noticeable increase during the rainy season when mosquito breeding intensifies (Department of Disease Control, 2024). These outbreaks highlight the continuing need for effective mosquito control measures at household and community levels.

Mosquito coils are among the most widely used insect control products due to their low cost, ease of use, and effectiveness in reducing mosquito populations in residential environments. The increasing demand for mosquito coils has driven manufacturers to operate continuous production processes, where efficiency, product quality, and energy consumption play critical roles in determining production costs and operational competitiveness. In such manufacturing systems, energy efficiency has become an important concern, as thermal processes account for a significant proportion of total industrial energy consumption. Improving energy efficiency in industrial processes not only reduces operational costs but also enhances system performance and sustainability (International Energy Agency, 2022).

One of the most critical stages in mosquito coil manufacturing is the drying process, which directly affects moisture content, mechanical strength, and overall product quality. In industrial applications, drying systems are commonly supplied by steam boilers due to their ability to provide stable and controllable thermal energy. However, previous studies have shown that the performance of industrial steam systems is often limited by factors such as scale formation, poor feedwater quality, and inefficient steam distribution, all of which can significantly reduce boiler efficiency and increase fuel consumption (Kaya & Eyidogan, 2010).

In the case study factory examined in this research, a central steam boiler supplies steam to five drying chambers used in mosquito coil production. Operational problems were identified in both the boiler and drying systems, including slow steam generation and insufficient steam supply during peak production periods. These problems were primarily caused by scale accumulation inside the boiler tubes and inappropriate feedwater quality characterized by high alkalinity. As a result, heat transfer efficiency was reduced and fuel consumption increased, leading to unstable steam supply to the drying chambers.

Consequently, the drying process required significantly longer operating times. The drying duration increased from the original 6–7 hours to 8–9 hours per batch, resulting in higher energy consumption, increased production costs, and unstable temperature profiles inside the drying chambers. Temperature fluctuations caused non-uniform drying and led to a high proportion of defective products, including surface whitening, warping, cracking, bending, and breakage. These defects reduced production yield and increased material waste, thereby negatively affecting overall operational efficiency.

From an industrial engineering and operations management perspective, improving boiler performance and optimizing steam distribution are essential for enhancing drying efficiency, stabilizing process conditions, and reducing energy consumption. Therefore, this study aims to investigate the operational performance of the steam boiler and drying chambers in a mosquito coil manufacturing process and to implement process improvements focused on boiler cleaning and drying system modification. The objectives of this study are to reduce drying time, improve temperature stability, decrease defective products, and lower production costs. The findings are expected to provide practical guidelines for energy-efficient process improvement in steam-based drying systems applicable to similar manufacturing industries.

1.1 Objectives

The objectives of this study are as follows

1.1.1. To investigate the operational characteristics and performance of the mosquito coil drying process in a selected case study factory, focusing on the steam supply system and temperature control within the drying chambers.

1.1.2. To analyze the types and root causes of defects generated during the mosquito coil drying process by examining the relationship between drying conditions and product quality.

1.1.3. To develop and implement process improvement approaches aimed at enhancing drying efficiency, reducing processing time, minimizing defects, and lowering production costs through improvements in the steam boiler and drying chamber systems.

2. Literature Review

2.1 Steam Boiler Performance and Energy Efficiency

Steam boiler systems are widely used in industrial manufacturing processes that require thermal energy, such as drying, heating, and sterilization. Boilers play a critical role in determining overall energy efficiency and process stability, particularly in industries that rely on continuous production systems. According to the International Energy

Agency (IEA, 2022), industrial thermal processes account for a significant share of total energy consumption, and steam systems represent one of the largest opportunities for energy efficiency improvement in manufacturing sectors.

Previous studies have identified several factors that negatively affect boiler performance, including scale formation, improper feedwater quality, and inefficient heat transfer. Kaya and Eyidogan (2010) reported that scale accumulation on heat transfer surfaces significantly reduces boiler efficiency and increases fuel consumption, leading to higher operational costs. In addition, poor water quality, especially high alkalinity, accelerates scale formation and contributes to unstable steam generation. These issues highlight the importance of boiler maintenance and water treatment in achieving efficient steam production.

2.2 Drying Processes in Industrial Manufacturing

Drying is a critical unit operation in many manufacturing industries, as it directly influences product quality, mechanical strength, and moisture content. Inadequate drying conditions often result in extended processing time, excessive energy consumption, and inconsistent product quality. Mujumdar (2014) and Smith (2016) emphasized that industrial drying systems must be designed and operated to achieve uniform heat distribution and stable temperature control in order to prevent defects and reduce energy waste.

Steam-based drying chambers are commonly used due to their ability to provide indirect heating and stable thermal energy. However, several studies have reported that inefficient steam distribution and improper control strategies lead to temperature fluctuations within drying chambers. These fluctuations cause non-uniform drying, which can result in defects such as cracking, warping, and surface discoloration (Mujumdar, 2014). Therefore, optimizing steam supply and improving temperature control are essential for enhancing drying performance.

2.3 Relationship Between Process Stability and Product Quality

Process stability is a key factor affecting product quality in manufacturing systems. Unstable temperature profiles and inconsistent energy input often lead to variations in product characteristics and increased defect rates. Vakalis et al. (2019) and Montgomery (2019) stated that maintaining stable process parameters is essential for reducing variability and improving quality outcomes in industrial processes. In drying operations, temperature deviations from set values can significantly affect moisture removal rates and material properties.

Several studies have shown that improving process control and stabilizing operating conditions can effectively reduce defects and increase production yield. By minimizing temperature fluctuations and ensuring uniform heat transfer, manufacturers can achieve more consistent product quality while reducing rework and material waste. These findings support the importance of integrating process control improvements with equipment optimization in industrial drying systems.

2.4 Research Gap

Although previous studies have extensively examined energy efficiency in steam boiler systems and optimization of industrial drying processes, most research has focused on large-scale industries such as food processing, chemical production, and pulp and paper manufacturing. Limited studies have addressed process improvement in mosquito coil manufacturing, particularly in the context of steam boiler performance and drying chamber efficiency. Moreover, few studies have investigated the combined effects of boiler maintenance, steam distribution improvement, and drying process optimization on production time, defect reduction, and cost savings in small-to-medium-scale manufacturing facilities.

Therefore, there is a need for a practical, case-based study that integrates boiler performance improvement with drying process optimization to enhance energy efficiency and product quality in mosquito coil manufacturing. This study aims to fill this gap by applying industrial engineering principles to improve steam generation, stabilize drying conditions, and reduce defects in a real manufacturing environment.

3. Methods

This study applies a case study–based process improvement methodology in a mosquito coil manufacturing factory. The objective is to evaluate and improve the performance of the steam boiler and drying chamber systems used in the drying process. A before-and-after comparison approach was employed to assess the effectiveness of the implemented improvements.

The research focused on identifying operational problems related to insufficient steam supply, unstable drying temperatures, long drying time, and high defect rates. Based on preliminary observations and process analysis, improvement actions were designed and implemented at both the steam generation system (Boiler) and the steam utilization system (Drying chambers).

The methodology consisted of four main steps: (1) analysis of the existing drying process and steam system, (2) implementation of boiler and drying chamber improvements, (3) collection of operational data before and after improvement, and (4) performance evaluation based on drying time, temperature stability, and product quality.

4. Data Collection

Data collection was conducted to evaluate the performance of the drying process before and after the implementation of process improvements. The objective of data collection was to obtain quantitative and qualitative information related to drying time, temperature behavior, and product quality in order to assess the effectiveness of the improved steam boiler and drying chamber systems.

The study focused on two drying chambers supplied by a central steam boiler in the case study factory. Data were collected under normal production conditions to ensure that the results reflected actual operational performance.

4.1 Temperature Data

Temperature data were collected from each drying chamber throughout the entire drying cycle. Two types of temperature values were recorded:
4.1.1. Set Value (SV) the target temperature programmed in the control system
4.1.2. Process Value (PV) the actual temperature measured inside the drying chamber
Temperature readings were recorded at 10-minute intervals from the beginning of the drying process until the end of the cycle. This data was used to evaluate temperature stability, control accuracy, and deviations between SV and PV before and after the process improvements.

4.2 Drying Time Data

Drying time was measured for each batch, starting from the initial heating stage until the products reached the required moisture condition for further processing. The total drying time was recorded in minutes and compared between the pre-improvement and post-improvement conditions to determine the effectiveness of the implemented changes in reducing processing time.

4.3 Product Quality and Defect Data

Product quality data were collected through visual inspection of dried mosquito coils after completion of the drying process. Defects were categorized based on observable characteristics, including surface whitening, warping, cracking, bending, and breakage. The occurrence of defects before and after the process improvement was recorded to evaluate the impact of improved temperature stability and drying efficiency on product quality.

4.4 Data Collection Period

Data were collected over multiple production cycles to ensure consistency and reliability of the results. All data collection activities were performed using the same operating conditions, product specifications, and inspection criteria to minimize variability unrelated to the process improvements.

5. Results and Discussion

This section presents the results of the performance improvement of the steam boiler and drying chamber systems in the mosquito coil production process. The results are analyzed by comparing the system performance before and after the implementation of improvement measures, using both numerical and graphical analyses. The evaluation focuses on key performance indicators including drying time, temperature control within the drying chamber, and trends in defect reduction during the production process.

The analysis in this section is divided into four main parts. The first part presents the numerical results to quantify the changes in drying time before and after the improvement. The second part provides graphical results to illustrate the temperature profiles and the stability of the drying process. The third part discusses the proposed improvements and their contributions to process efficiency enhancement. Finally, the validation section is included to verify the reliability and consistency of the obtained results.

The results are discussed from an engineering perspective to demonstrate the relationship between the improved steam supply system and the enhanced performance of the drying chambers. In addition, the impact of the improvement on production efficiency and operational cost reduction is emphasized. The findings highlight the practical value of applying process improvement strategies in real industrial manufacturing environments.

5.1 Numerical Results

Table 1. Comparison of Average Drying Time Before and After Improvement

Drying Chamber	**Average Drying Time (Before) (min)**	**Average Drying Time (After) (min)**	**Time Reduction (min)**	**Reduction (%)**
A	410	340	70	17.07
B	460	390	70	15.22

Based on Table 1., the results indicate that after the improvement of the steam boiler and drying chamber systems, the drying time of both Drying Chamber A and B was significantly reduced. Drying Chamber A achieved a reduction in drying time of 70 minutes, corresponding to a decrease of 17.07%, while Drying Chamber B exhibited a reduction of 70 minutes, or 15.22%, compared to the conditions prior to the improvement.

The reduction in drying time reflects the enhanced heat transfer efficiency of the drying system, which resulted from improved stability of the steam supply from the boiler, as well as enhancements in the control devices and steam distribution within the drying chambers. These improvements enabled the drying temperature to reach the desired operating range more rapidly and to be maintained more consistently throughout the process.

From a production perspective, the reduction in drying time by approximately 1–2 hours per production cycle significantly increases the throughput of the drying process, allowing a higher number of production cycles per day. Moreover, the shorter duration of thermal energy usage directly contributes to a reduction in fuel consumption and overall energy costs of the production process. These outcomes are consistent with the objectives of improving the efficiency of the drying system addressed in this study.

5.2 Graphical Results

Figure 1. shows the temperature profiles of Drying Chamber A before and after the improvement. Before the improvement, the process temperature exhibited noticeable fluctuations and a slower heating response, indicating insufficient steam supply and unstable heat transfer within the drying chamber. After the improvement, the temperature increased more steadily and closely approached the desired operating temperature of approximately 65 °C. The reduced temperature fluctuation and improved stability demonstrate enhanced thermal control of the drying process, resulting in a shorter drying time and improved product quality.

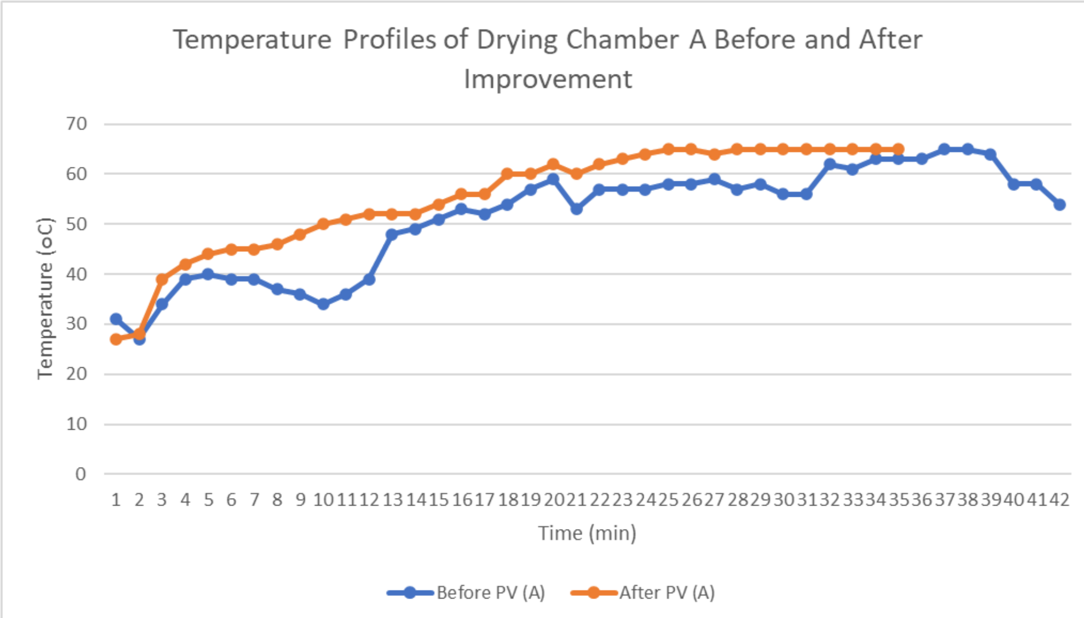

Figure 1. Temperature Profiles of Drying Chamber A Before and After Improvement

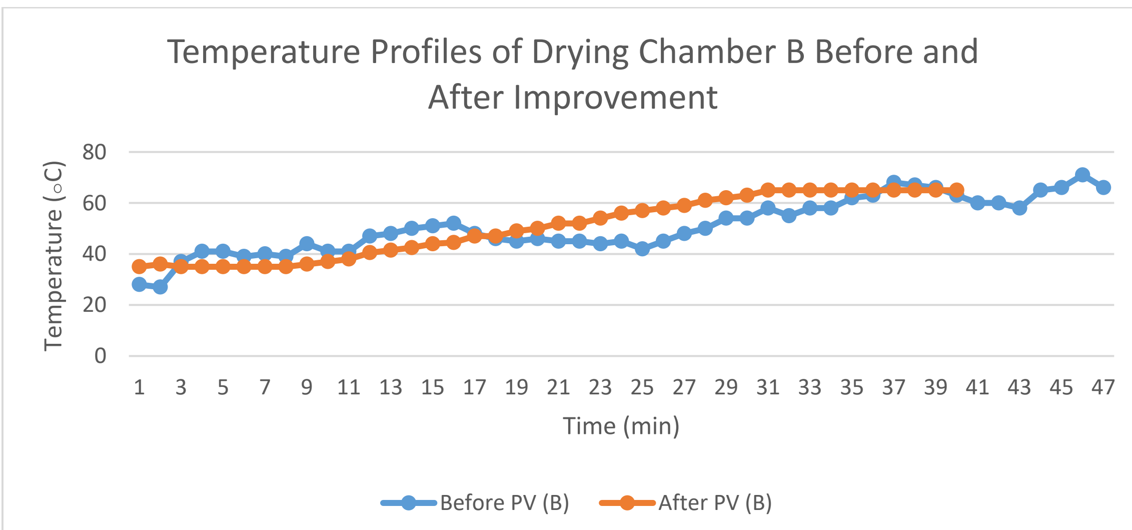

Figure 2. Temperature Profiles of Drying Chamber B Before and After Improvement

Figure 2. presents the temperature profiles of Drying Chamber B before and after the improvement. Prior to the improvement, the temperature profile shows noticeable fluctuations and an unstable heating pattern, indicating inconsistent steam supply and limited thermal stability within the chamber. After the improvement, the temperature increases more gradually and remains closer to the target operating temperature of approximately 65 °C for most of the drying period.

Although a temporary temperature drop is observed during the early stage of the post-improvement profile, the overall trend demonstrates improved thermal stability and a more consistent heating behavior compared to the pre-improvement condition. The improved temperature control contributes to enhanced drying performance and supports the reduction in drying time observed in the numerical results. These results confirm that the implemented improvement measures are effective and applicable across different drying chambers.

5.3 Proposed Improvements

Based on the numerical and graphical analysis results, the implemented improvements have effectively reduced drying time and enhanced temperature stability in the drying process. However, additional improvement measures are proposed to further enhance the long-term efficiency and sustainability of the drying system (Saidur et al., 2010).

First, the implementation of a preventive maintenance program for the steam boiler is recommended. Regular boiler cleaning and inspection should be scheduled to prevent scale accumulation, which has been identified as a major factor affecting steam generation efficiency. Kaya and Eyidogan (2010) reported that scale formation and inadequate maintenance significantly reduce the efficiency of industrial steam systems and increase energy consumption. In addition, controlling feedwater quality, such as pH level and water hardness, can further reduce scale formation and improve the thermal performance of the boiler.

Second, continuous monitoring of steam pressure and temperature at the inlet of each drying chamber is proposed. The installation of monitoring sensors combined with a basic monitoring system would enable early detection of steam supply fluctuations and help maintain stable operating conditions. This approach is consistent with industrial energy efficiency recommendations proposed by the International Energy Agency (2022), which emphasize that continuous monitoring and control of energy-related parameters play a crucial role in reducing energy losses and improving process stability.

Third, the improvement measures implemented in this study should be extended to all drying chambers within the production line. Standardizing valve sizing, control devices, and steam distribution configurations across all chambers can enhance consistency in drying performance and reduce variations in product quality. Such standardization in steam systems has been recognized as an effective approach to improving overall system efficiency in industrial processes (Incropera et al., 2007 & Kaya and Eyidogan, 2010 & ISO., 2018).

Finally, future improvements may include the optimization of drying parameters, such as temperature ramp rates and holding times, according to product characteristics. Optimizing these parameters can further improve energy efficiency while maintaining product quality, which aligns with the principles of process optimization and efficient energy utilization in industrial manufacturing (Bejan, A. 2013 & International Energy Agency, 2022)

5.4 Validation

The effectiveness of the proposed improvement measures was validated by comparing the system performance before and after the implementation using both numerical indicators and temperature profile analysis. The validation focused on drying time reduction and temperature stability, which are critical performance indicators of the drying process.

The numerical results demonstrate a consistent reduction in drying time for both Drying Chamber A and Drying Chamber B after the improvement. Drying time was reduced by approximately 70 minutes in both chambers, corresponding to reductions of 17.07% and 15.22%, respectively. The consistency of time reduction across different chambers confirms that the improvement measures are not case-specific and can be reliably applied to multiple drying units.

In addition, the graphical results further validate the improvement outcomes. The temperature profiles after the improvement exhibit a faster heating response and reduced fluctuations compared to the pre-improvement condition. The process temperature remains closer to the desired operating temperature of approximately 65 °C for most of the drying period, indicating improved thermal stability and more effective heat transfer within the drying chambers.

These findings are consistent with previous studies on industrial steam systems and drying processes. For example, Kaya and Eyidogan (2010) reported that improving heat transfer efficiency in steam boiler systems can significantly enhance thermal performance and reduce energy losses. Similarly, Mujumdar (2014) emphasized that stable temperature conditions are essential for achieving uniform drying and improving product quality in industrial drying systems.

The agreement between numerical reductions in drying time and graphical evidence of improved temperature control provides strong validation of the proposed improvements. These results confirm that the enhancement of steam supply stability and control mechanisms leads to measurable and reliable improvements in drying performance. Therefore, the implemented improvement measures are validated as effective solutions for improving efficiency and consistency in industrial drying processes.

6. Conclusion

This study investigated the improvement of the steam boiler and drying chamber systems in a mosquito coil manufacturing process with the objective of reducing drying time, improving temperature stability, and enhancing overall production efficiency. The improvement measures focused on stabilizing steam supply, enhancing heat transfer efficiency, and optimizing drying chamber operation.

The numerical results demonstrate that the proposed improvements successfully reduced the drying time of both Drying Chamber A and Drying Chamber B by approximately 70 minutes, corresponding to reductions of 17.07% and 15.22%, respectively. These reductions directly contributed to increased production throughput and reduced energy consumption per production cycle. In addition, the graphical results revealed that the temperature profiles after the improvement exhibited faster heating responses and significantly reduced fluctuations, allowing the process temperature to remain closer to the desired operating temperature of approximately 65 °C.

The validation results confirmed that the observed improvements were consistent across different drying chambers and were supported by both numerical indicators and temperature profile analysis. This consistency indicates that the proposed improvement measures are reliable and applicable beyond a single case, demonstrating robustness in practical industrial operation.

The main contribution of this study lies in the practical application of steam system improvement and drying chamber optimization in a real industrial setting. The findings provide useful guidelines for similar manufacturing processes that rely on steam-based drying systems. Future work may focus on further optimization of drying parameters and the implementation of advanced monitoring systems to enhance energy efficiency and process sustainability.

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Biographies

Mr. Chisanapong Photikamolpat currently serves as Production Manager and Quality Management Representative (QMR) at Fumakilla (Thailand) Co., Ltd. He has over 15 years of experience in production management, quality control, and process improvement within the industrial sector. He holds a Bachelor's degree in Mechanical Engineering from Rajamangala University of Technology, Northeastern Region, and is currently pursuing a Master's degree in Systems Engineering at Suranaree University of Technology. Throughout his professional career, he has held positions including Production Supervisor, Production Engineer, and Production Manager in leading companies.

His areas of expertise include Lean Manufacturing, Total Productive Maintenance (TPM), ISO 9001:2015, GMP, FMEA, APQP, PPAP, project management, and manufacturing process efficiency improvement. He has also participated in a Lean Manufacturing project competition and was awarded First Prize at the Northeastern Regional Level under a program organized by the Technology Promotion Association (Thailand–Japan). This achievement reflects his strong ability to apply Lean principles to eliminate waste, enhance production efficiency, and deliver tangible results for organizations. In addition, he plays an active role in Energy Management as an Assistant Energy Manager, with experience in planning, controlling, and improving energy utilization to increase efficiency and reduce operational costs. He has completed training and gained knowledge in Energy Management Systems and Energy Auditing. Mr. Chisanapong possesses strong leadership, analytical thinking, problem-solving, and communication skills. He is able to perform effectively under pressure and is committed to driving sustainable organizational improvement in terms of Quality, Cost, and Delivery (QCD).

Pornsiri Jongkol is a lecturer in School of Industrial Engineering and also the Dean of Engineering. She obtained the degree of Ph.D. in 2000 in Industrial Engineering from Dalhousie University, Canada.