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Analysis of the Effect of Position and Dimension of Infrared Burner on Heat Distribution and Efficiency of Butterfly Pea Flower Drying Oven

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Abstract

Drying is a process of reducing the moisture content of materials using thermal energy. A drying oven equipped with infrared burner technology offers improved efficiency for drying butterfly pea flowers (Clitoria ternatea); however, uneven heat distribution remains a challenge. This unevenness can result in non-uniform drying, prolonged drying times, and reduced final product quality. This study employs Computational Fluid Dynamics (CFD) simulations to model the heat transfer process within the drying oven. Six different configurations of burner positions and dimensions were examined to evaluate their effects on heat distribution and drying rates. The results indicate that more uniform heat distribution is achieved with non-aligned burner positions, while larger burner sizes generally produce better heat distribution and faster drying rates. This research highlights the importance of optimizing burner position and dimensions to maximize drying efficiency and ensure consistent product quality.

Introduction

Drying is a fundamental process that utilizes heat energy to reduce the water content of a material (Atuonwu et al., 2011). The material with reduced water content becomes the final product of this procedure. During the drying process, unsaturated air is blown onto the object being dried, which assists in evaporating the water. Butterfly pea flowers can be dried traditionally using sunlight, which takes approximately two days, or more quickly using a drying oven (Astadewi et al., 2024). The oven method is designed to address the challenges of natural drying, such as weather uncertainty, and provides a more continuous and regulated procedure (Soekarno et al., 2023; Aghbashlo et al., 2015; Pandey et al., 2024).

Uneven heat distribution in ovens often poses a threat to oven users, both in household kitchens and food processing industries (Syamsul Rahman, 2021). This issue can lead to adverse effects, such as unevenly cooked food, longer cooking times, poor food quality, and high energy consumption. Various factors contribute to this problem, including suboptimal oven design, malfunctioning heating elements, leaky oven doors, and improper oven usage. Understanding the causes and impacts of this issue is essential to ensure optimal cooking results and oven efficiency. Therefore, it is crucial to select well-designed ovens and regularly inspect the heating elements.

Sustainable production of butterfly pea flowers with high-quality yields can be efficiently enhanced using gas-powered infrared burners, which heat the flowers through infrared radiation (Mahendra et al., 2024). Faster drying times, larger capacities, uniform combustion, consistent heating, and energy efficiency are among its benefits. Large industries, small and

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medium enterprises, and households can all benefit from this technology (Bizzy et al., 2017; Guy & Arnold, 1995; Cowan, 2023). Drying ovens with infrared burner technology offer many advantages; however, uneven heat distribution within the oven often remains an issue. In a previous study (Diana, 2023), the heat distribution in such ovens was found to be uneven, with faster drying occurring on the right and left sides of the second rack. If this issue persists, the parts of the flowers exposed to excessive heat will dry faster than other parts receiving less heat. This can result in non-uniform drying of the processed product, potentially affecting the final product quality. Heat radiation emitted from the oven also poses a particular concern that needs to be addressed to improve operational safety (Suhardi, 2008).

Uneven heat distribution can cause several problems, including non-uniform drying of butterfly pea flowers, longer drying times, and even damage to the final product (Chong et al., 2023; Saha, 2019; Ayaquil, 2017). One potential factor influencing heat distribution is the position and dimensions of the infrared burner within the drying oven. Previous studies may have been limited to general aspects of heat distribution or may not have considered variations in the position and dimensions of the infrared burner specifically.

To better understand heat distribution within butterfly pea flower drying ovens, the use of Computational Fluid Dynamics (CFD) is crucial (Bie, 2014; An et al., 2024; Islas, 2022). CFD allows for detailed modeling of airflow and heat distribution inside the oven, as well as predicting the effects of various design and operational factors. By utilizing CFD, areas with uneven heat distribution can be identified, and strategies can be developed to improve the efficiency and quality of the drying process (Ambarita, 2011).

Many studies on heat distribution in drying ovens remain limited to simple modeling or physical testing that does not consider the complexities of airflow and heat transfer within the oven in detail. Therefore, studies employing a more comprehensive approach, such as CFD simulations, are necessary to gain a deeper understanding of heat distribution phenomena in butterfly pea flower drying ovens.

A previous study Febrian & Anggara (2023) emphasized the importance of analyzing heat distribution in drying machines using CFD simulation methods. Validation tests demonstrated the accuracy of the simulation results, with an error margin of less than 5%, confirming the consistency between the simulated heat distribution and actual distribution. Other research references also support these findings, with several previous studies discussing CFD analysis of heat distribution in drying equipment (Tegenaw et al., 2019; Aktaş et al., 2017; Masud et al., 2019).

Based on the aforementioned background issues, this study aims to analyze the effect of varying the position and dimensions of infrared burners in butterfly pea flower drying ovens on heat distribution. Understanding how these factors specifically contribute to heat distribution can assist in designing ovens that improve drying efficiency and the final product quality when using infrared burner technology.

Methods

Heat transfer analysis was conducted on a butterfly pea flower drying oven using LPG gas. This research is essential to produce a more efficient butterfly pea flower drying tool. The butterfly pea flowers dry evenly due to uniform heat distribution within the oven, reducing the likelihood of burning in certain areas of the flowers.

In this study, the authors employed a simulation method. The research was conducted from July to December 2024 at the Faculty of Engineering Laboratory, Universitas Pembangunan Nasional Veteran Jakarta. The materials used in this research were a butterfly pea flower drying machine with dimensions of 50 cm in length, 50 cm in width, and 50 cm in height, and butterfly pea flowers with a sample weight of 1.4 kg.

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In this study, several governing equations were used to calculate the drying rate, drying efficiency, energy used for water evaporation, and the total energy supplied during the butterfly pea flower drying process. These equations were applied to evaluate the performance of the drying oven in terms of heat distribution and efficiency. The equations used are as follows:

The drying rate is defined as the amount of water evaporated from the flowers per unit of time. The equation used is::

$$R_d = \frac{m_i - m_f}{t} \quad (1)$$

Where m_i is the initial mass of the flowers (kg), m_f is the final mass of the flowers (kg), and t is the drying time (hours). This equation is derived from the basic concept of mass change over time ($\Delta m/\Delta t$) which is commonly used in mass transfer processes. By knowing the mass of evaporated water ($m_i - m_f$) and the drying time, the drying rate can be determined.

$$\mathrm{E} = \frac{\text{Energy for water evaporation}}{\text{Total energy supplied}} \times 100\% \quad (2)$$

The drying efficiency equation is defined as the ratio between the energy used to evaporate water and the total energy supplied by the heating device. This efficiency indicates how effectively the supplied energy is utilized for the water evaporation process. The efficiency value is calculated by comparing the actual energy used to evaporate water with the total electrical energy consumed by the heating device.

$$Q = m_w \times L_v \quad (3)$$

Where m_w is the mass of evaporated water (kg), obtained from the difference between the initial and final mass of the flowers ($m_i - m_f$) and L_v yaitu panas laten penguapan (2260 kJ/kg). s the latent heat of vaporization (2260 kJ/kg). This equation originates from thermodynamic principles, where the latent heat of vaporization represents the energy required to convert liquid water into vapor without a change in temperature. The L_v Value for water is 2260 kJ/kg.

The total energy supplied by the heating device during the drying process is calculated as:

$$E_t = P \times t \quad (4)$$

Where P is the power of the heating device (kW), and tt is the drying time (hours). This equation is based on the fundamental principle of electrical energy, where the energy consumed by the heating device is the product of electrical power P and drying time t.

Results and Discussion

The testing was conducted using six different geometric configurations, consisting of three burner dimensions and two burner positions. In the first experiment, the burner was placed in Position 1 with dimensions of 22 x 17 cm. The second experiment was carried out with the burner in Position 1 and dimensions of 29.5 x 12 cm, while the third experiment used the burner in Position 1 with dimensions of 33.5 x 10 cm. Subsequently, the fourth experiment used the burner in Position 2 with dimensions of 22 x 17 cm. In the fifth experiment, the burner was placed in Position 2 with dimensions of 29.5 x 12 cm, and finally, the sixth experiment was conducted with the burner in Position 2 and dimensions of 33.5 x 10 cm..

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Variations of burner positions (position 1 and 2) with burner dimensions: 22 x 17 cm, burner 29.5 x 12, and burner 33.5 x 10 cm

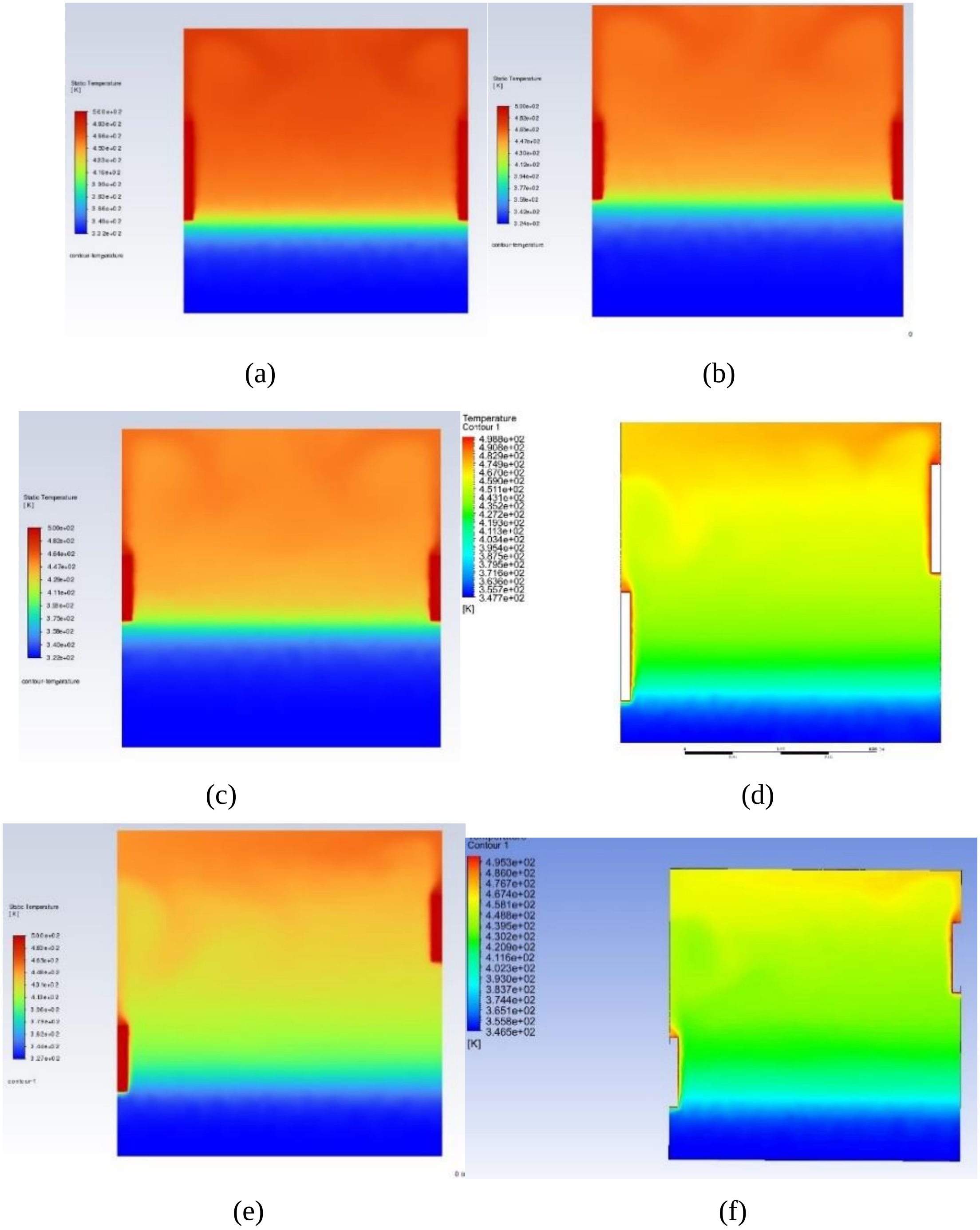

Figure 1. Burner Variation, (a) Variations of burner positions 1 22 x 17 cm, (b) Position 1 burner with dimensions 29.5 x 12 cm, (c) Position 1 burner with dimensions 33.5 x 12 cm, (d) Position 2 burner with dimensions 22 x 17 cm, (e) Position 2 burner with dimensions 29.5 x 12 cm, (f) Position 2 burner with dimensions 33.5 x 12 cm

Based on the analysis of the six images depicting variations in the position and dimensions of the heating element on heat distribution within the drying chamber in Figure 1, it is evident that there are significant differences in the uniformity of heat distribution. In image (a), heat is concentrated in the center of the drying chamber, resulting in the edges and corners receiving significantly lower temperatures. This leads to uneven heat distribution with a sharp temperature gradient. In image (b), heat coverage improves compared to image (a). The heat

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begins to spread towards the edges, but there are still temperature differences between the center and other parts, indicating that the distribution is not yet fully uniform.

The heat distribution in image (c) shows a significant improvement. Heat is more evenly distributed across the chamber, including the edges and corners, which previously exhibited lower temperatures in the earlier images. This more uniform heat distribution is indicated by a smaller temperature gradient, reflecting better temperature consistency. In image (d), the heat distribution pattern shows further improvement, with broader coverage compared to images (a) and (b). Nevertheless, some corner areas still receive lower temperatures, indicating that the distribution is not yet fully uniform.

In image (e), the heat distribution improves further, with heat reaching almost the entire drying chamber. The previously cooler corner areas show an increase in temperature, and the temperature gradient becomes smaller, indicating more uniform heat distribution compared to the previous configurations. In image (f), the heat distribution reaches its most optimal level. Heat is evenly spread throughout the chamber, with no significant cold spots. The very small temperature gradient demonstrates that temperatures across the chamber are nearly uniform, creating optimal conditions for the drying process.

From the overall analysis, image (f) exhibits the most uniform and optimal heat distribution compared to the other images. These results indicate that broader heat coverage and a strategically placed heating element significantly affect the uniformity of heat distribution in the drying chamber, as stated in the study by Febrian & Anggara (2023). Their research concluded that the more precise the placement and dimensions of the heat conductor, the fewer areas within the drying machine experience low temperatures. This is crucial to ensure an efficient drying process, where all areas in the drying chamber receive sufficient heat.

The Effect of Variations on the Drying Rate of Butterfly Pea Flowers

The drying rate is significantly influenced by the heat distribution within the drying chamber. The more evenly heat is distributed, the more uniform the temperature received by the material inside the chamber, allowing the moisture in the butterfly pea flowers to be released more quickly. Among the six images analyzed, the image with the most uniform heat distribution (image (f)) produces the most optimal drying rate because all flowers receive consistent temperatures. In contrast, the image with uneven heat distribution (image (a)) causes some areas of the flowers to experience inadequate heating, resulting in a slower drying process.

Table 1. Results of the Drying Rate of Butterfly Pea Flowers

Figure	Burner Positions	Burner Dimension	Drying Time (t)	Drying Rate (R_d)
a	Aligned	22 × 17 cm	6 Hours	0.163 kg/Hours
b	Aligned	29.5 × 12 cm	5 Hours	0.196 kg/Hours
c	Aligned	33.5 × 10 cm	4 Hours	0.245 kg/Hours
d	Non-Aligned	22 × 17 cm	5.5 Hours	0.169 kg/Hours
e	Non-Aligned	29.5 × 12 cm	4.5 Hours	0.217 kg/Hours
f	Non-Aligned	33.5 × 10 cm	4 Hours	0.245 kg/Hours

Based on Table 1, which presents the drying results of butterfly pea flowers, there are significant differences in the drying rate (R_d) b ased on the variations in the position and dimensions of the infrared burner. In the aligned burner position, it is observed that the drying rate increases with larger burner dimensions. The configuration with the largest dimensions, 33.5 × 10 cm (image c), achieves the highest drying rate of 0.245 kg/hour with a drying time

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of 4 hours. Meanwhile, for smaller burners such as 22 × 17 cm (image a), the drying rate is lower at 0.163 kg/hour, with a drying time of 6 hours.

In the non-aligned burner position, a similar pattern is observed, where the drying rate increases with larger burner dimensions. The largest burner configuration (image f) also achieves the highest drying rate of 0.245 kg/hour, similar to the aligned configuration; however, longer drying times are observed for smaller dimensions (images d and e).

From the comparison of burner positions, it is evident that the non-aligned position results in shorter drying times compared to the aligned position for the same burner dimensions. This indicates that the more direct and uniform heat distribution in the non-aligned position improves drying efficiency. Overall, burners with large dimensions (33.5 × 10 cm) deliver the best performance in both positions, achieving the highest drying rate and relatively short drying times, making it the most efficient configuration for drying butterfly pea flowers.

The Effect of Variations on Drying Efficiency

Drying efficiency refers to the ability of the equipment to utilize thermal energy to reduce the moisture content of the material. Variations in the position and dimensions of the infrared burner influence how effectively the heat is absorbed by the butterfly pea flowers. Uniform heat distribution tends to improve efficiency by minimizing heat loss to unnecessary areas.

Table 2. Results of Drying Efficiency for Butterfly Pea Flowers

Figure	Burner Positions	Burner dimensions	Time (t)	Evaporation Energy (Q)	Total Energy (E_t)	Efficiency(E)
a	Aligned	22 × 17 cm	6 Hours	2214.8 kJ	4320 kJ	51.3%
b	Aligned	29.5 × 12 cm	5 Hours	2214.8 kJ	3600 kJ	61.52%
c	Aligned	33.5 × 10 cm	4 Hours	2214.8 kJ	2880 kJ	76.9%
d	Non-Aligned	22 × 17 cm	5.5 Hours	2214.8 kJ	3960 kJ	55.92%
e	Non-Aligned	29.5 × 12 cm	4.5 Hours	2214.8 kJ	3240 kJ	68.35%
f	Non-Aligned	33.5 × 10 cm	4 Hours	2214.8 kJ	2880 kJ	76.9%

Based on Table 2, the drying efficiency results for butterfly pea flowers indicate that drying efficiency (E) is influenced by the position of the infrared burner, burner dimensions, and drying time. In the aligned position, the efficiency tends to be lower compared to the non-aligned position, especially for smaller burner dimensions. For instance, the 22 × 17 cm burner in the aligned position (image a) has an efficiency of 51.3%, while in the non-aligned position (image d), it increases to 55.92%. Additionally, efficiency increases with larger burner dimensions. The largest dimension, 33.5 × 10 cm, results in the highest efficiency of 76.9% for both positions (image c for aligned and image f for non-aligned). This indicates that heat is more evenly distributed with a larger burner, allowing energy to be more optimally used for evaporation. Overall, the best configuration for drying efficiency is using a 33.5 × 10 cm burner in both aligned and non-aligned positions, although the non-aligned position tends to provide better efficiency with smaller burners.

Conclusion

Based on the conducted study, the analysis of heat distribution with variations in burner position and dimensions in the drying chamber is significantly influenced by the position and dimensions of the infrared burner. Image (f) with the 33.5 × 10 cm burner in position 2 shows the most even heat distribution compared to the other images, resulting in the highest drying rate (0.245 kg/hour) and the best drying efficiency (76.9%). Conversely, image (a) with the 22 × 17 cm burner and image (b) with the 29.5 × 12 cm burner in position 1 show less uniform heat distribution, leading to a lower drying rate and efficiencies of only 51.3% and 61.52%,

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respectively. The use of the 33.5 × 10 cm burner in both aligned and non-aligned positions results in good drying rates and efficiency, but the non-aligned position tends to provide better efficiency for smaller burners. The burner configuration in image (f) allows heat to spread optimally throughout the chamber, making energy use more effective in evaporating water from the butterfly pea flowers. This demonstrates that an optimal burner design and dimension enhance heat distribution, speed up drying, and improve energy efficiency. Image (f) is the best configuration for the butterfly pea drying process.

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