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Research Paper

Design and Performance Analysis of an Innovative Flow Door in a Brick-Based Dual-Bin Compost Mixing System

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Abstract

Compost production in Indonesia is often hampered by conventional methods that rely on manual mixing, resulting in lengthy processing times, high labor requirements, and inconsistent compost quality. This study aimed to develop a mechanical compost mixer system featuring an innovative flow gate in a dual-brick-bin setup. The innovation is designed to improve mixing efficiency, mixture homogeneity, and energy consumption. The research was conducted in Tanjung Tebal Village, Lahat Regency, from March to June 2024, using materials such as household organic waste, animal manure, coffee husks, dry leaves, fresh leaves, and the EM4 bioactivator.

The methodology investigated using a comparison of a 9HP gasoline engine and equipped with the innovative flow gate to manual methods. Parameters compared include mixing time, energy consumption, homogeneity distribution, and residual material. The results show the mechanical system reduced mixing time by up to 30% from an average of 45 minutes using manual methods to 30 minutes, mixture homogeneity increased to 95% compared to 70% with manual methods, while residual material decreased from 15% to 6%. The flow gate innovation in the dual-brick-bin system proved effective in enhancing the efficiency of the compost mixing process. Implementation of this technology has the potential to support organic waste management in rural areas, reduce environmental pollution, and promote sustainable agriculture. Further research is recommended to evaluate the system's efficiency on a larger scale.

Keywords

Dual-brick-bin; Waste management efficiency; Compost; Mechanical mixing; Innovative flow gate; Mixture homogeneity

1. INTRODUCTION

Fundamental Theory of Composting

Composting in an agrarian country generates large quantities of organic waste annually, primarily from the agricultural, household, and livestock sectors (Setiawan et al., 2021). One effective way to process this waste is by producing compost—a natural degradation process converting organic waste into fertilizer (Suhartbyo, 2021). However, waste processing methods that employ manual mixing are often inefficient, time-consuming, and labor-intensive, posing a significant obstacle to optimizing waste management efforts (Rainmawati and Zulkarnain, 2023). Challenges in conventional compost production are detailed, such as achieving mixture homogeneity due to basic manual methods (Aditya and Purnomo, 2024). Inhomogeneity impacts the quality of compost, making it less than prime as a fertilizer (Suryadi et al., 2023). The use of machines requires more efficient transfer of materials between bins, reducing mixing time by 30% compared to manual methods (Setiawan et al., 2021). This paper aims to analyze the performance efficiency of the innovative flow gate in the dual-brick-bin system.

2. Literature Review

2.1 Theoretical Basis of Composting

Composting is the decomposition process of organic materials by microorganisms under controlled conditions, resulting in compost as a natural fertilizer. This process requires proper aeration to support aerobic microorganisms. The composting mixer functions to improve air circulation and heat distribution, accelerating decomposition. The use of brick baskets maintains the optimal temperature for microorganisms (Prasetyo, 2018; Wahyudi et al., 2018; Sutrisno, 2019).

2.2 Compost Mixer Technology

The compost mixer is crucial for the homogeneity of the mixture, aeration, and speeding up decomposition. Manual stirring is effective for small-scale operations, but mechanical tools are more efficient, reducing fermentation time by 30-40% (Prasetyo, 2018). Mixer designs vary, such as rotary drums and two-basket systems with flow doors, which enhance composting efficiency (Handayani and Purwanto, 2017; Aditya and Purnomo, 2024). Controlling aeration and moisture is a key factor in compost stability and maturity (Liu et al., 2019). Compost produced through a controlled process has also been shown to improve soil fertility and plant growth (Gutierrez-Miceli et al., 2021).

2.3 Flow Door Design and Two-Basket System

A well-designed flow door is essential for improving efficiency and operational ease of the compost mixer. The flow door was constructed with dimensions of 20 cm in height, 30 cm in width, and 5 cm in thickness, using 2 mm thick galvanized iron as the primary door material. These specifications were selected to ensure durability, optimal flow control, and ease of integration into the brick-based dual-bin composting system. Handayani and Purwanto (2017) found that a good flow door design can speed up the composting process by improving aeration and facilitating the transfer of compost between baskets.

2.4 Efficiency Factors and Compost Quality

Ergonomic design is important for ease of use. Equipment that is easy to operate and maintain will be more efficient, improve compost quality, and enhance user comfort.

2.5 Case Studies and Previous Research

Studies show that compost mixers with flow doors can accelerate decomposition by up to 30% and improve compost quality. The application of this technology supports the efficiency and sustainability of composting (Yulianti et al., 2020; Iskandar and Haryanto, 2017).

2.6 Conceptual Framework

An efficient composting process depends on aeration, temperature, and mixture homogeneity. Innovations like the two-basket brick system with flow doors overcome the limitations of manual stirring, improve efficiency, accelerate decomposition, and produce high-quality compost. This research aims to enhance mixture homogeneity, speed up composting, reduce residue, and optimize tool performance.

3. METHODOLOGY

3.1 Research Location and Duration

The research was conducted in Tanjung Tebat Village, Tanjung Tebat District, Lahat Regency, South Sumatra Province, over a period of four months (March–June 2024). The site was selected due to its favorable environmental conditions for composting and the availability of local organic materials.

3.2 Research Materials and Equipment

Research materials were household organic waste, animal manure, coffee husks, dry leaves, EM4 bioactivator, clean water, the ratio of wet to dry materials was 3:1. Meanwhile research tools were dual-brick-bin system with flow gate, HP compost mixer, pH meter, organic material chopper, water sprayer, buckets and shovels and camera for documentation.

3.3 Research Design

This study employed a quantitative experimental approach, comparing three composting methods: (1) the innovative method (dual-brick-bin with flow gate), (2) the conventional method (without flow gate), and (3) the manual method. The parameters analyzed included time efficiency, compost quality, energy usage, and temperature.

3.4 Research Procedure

The procedure involved preparing equipment and materials, chopping organic matter, and conducting composting using three methods:

- Innovative method: Materials transferred between bins using a flow gate.
- Conventional method: Manual transfer between bins.
- Manual method: Composting without bins, manually mixed.

3.5 Flow Gate Installation Mechanism

The flow gate was installed between two brick bins to facilitate material transfer and aeration. It was constructed from durable materials such as metal or processed wood and tested to ensure smooth material flow. The flow gate was strategically installed between two adjacent brick bins to facilitate both material transfer and passive aeration during the composting process. It was constructed from durable materials, including galvanized iron and processed hardwood, to withstand compost weight and environmental exposure. The distance between the two facing brick walls was maintained at 35 cm to accommodate the flow gate structure. The gate itself featured a rectangular frame measuring 30 cm in width and 20 cm in height, with a door panel thickness of approximately 5 cm. The galvanized iron sheet used had a thickness of 2 mm, providing a balance between strength and maneuverability. This design was tested to ensure smooth flow of compost material while allowing adequate air exchange between bins.

3.6 Descriptive Analysis

Data was collected through observation, equipment measurements, and visual documentation. Analyses included pH, moisture content, homogeneity, and physical compost quality. Statistical testing used ANOVA to identify significant differences between methods.

Table 1. Research Parameters

Parameter	Analytical Tool	Supporting Citation	Function in Research
pH (Compost)	Compost Thermometer	Haug (1993): "Neutral pH 6.5–7.5 indicates maturity and biological stability of compost."	Detects acidity or alkalinity
Moisture	Hygrometer	Alkarimiah and Suja (2019): "Ideal temperature during the maturation phase is between 30–40°C."	Assesses the maturity stage and decomposition stability
Physical Quality (color, texture, smell)	Visual Observation + Documentation	Zaman et al. (2020): "Dark brown color & fine texture indicate mature compost."	Qualitative evaluation of compost maturity
Method Differences	t-test and ANOVA	Field (2018): "t-test and ANOVA are valid for comparing independent groups."	Tests for statistical significance of differences between methods

Figure 1. Flow Door Design and Dimensions in the Two-Basket Brick System

4.2 Research Materials and Equipment

Research Materials:
Household organic waste, animal manure, coffee husk, dry leaves, EM4, and clean water. Wet and dry material ratio = 3:1. To optimize microbial activity and maintain appropriate moisture content, the composting blend consisted of a wet-to-dry material ratio of 3:1 (based on weight), where three parts of fresh organic waste were combined with one part of dry biomass such as leaves or husks.

Research Equipment:
Two-basket system with flow door. 9 HP mixer, pH meter, organic shredding tool, water sprayer, bucket, shovel, and documentation camera.

4.3 Research Design

This study uses a quantitative experimental approach with a comparison of three composting methods: innovative (two-basket system with flow door), conventional (without flow door), and manual. This study compared the effectiveness of three composting methods in terms of material transfer efficiency, decomposition rate, and compost quality:

1. **Innovative Method (Two-Bin System with Flow Door):** This system consists of two adjacent brick bins connected by a flow door. The door enables controlled movement of compost material from one bin to the other, facilitating efficient mixing and passive aeration. The design improves material turnover and reduces manual labor by leveraging gravity and directional flow during the turning process.
2. **Conventional Method (Two-Bin System without Flow Door):** This approach also utilizes two adjacent brick bins, but without any flow door. Material transfer between bins must be done manually using shovels or hoes. While it supports batch composting, this method is less efficient in terms of labor and time due to the lack of an integrated transfer mechanism.
3. **Manual Method (Single Heap or Open Pile):** Composting is done on the ground without a bin system. Mixing and aeration are performed entirely by hand or with simple tools. Although this method requires the lowest structural investment, it demands the highest labor input and tends to produce uneven compost quality due to limited control over aeration and

moisture.

The analysis is conducted on time efficiency, compost quality, energy usage, and temperature during the process.

4.4 Research Procedure

The research procedure consists of the preparation of materials and tools, shredding of materials, and three composting methods:

Innovative Method: Materials are transferred between baskets through the flow door.

Conventional Method: Manual transfer between baskets.

Manual Method: Composting without baskets, manual stirring.

4.5 Flow Door Installation Mechanism

The flow door is installed between two brick baskets to facilitate material transfer and aeration. This door is made from durable materials, such as metal or processed wood, and is tested to ensure smooth material flow.

4.6 Descriptive Analysis

Data is collected through observations, tool measurements, and visual documentation, with analysis of pH, moisture, homogeneity, and physical quality of the compost. Statistical testing is performed using ANOVA to identify significant differences between methods.

5. RESULT AND DISCUSSION

Table 2. Research Data Summary

Main Parameter	Compared Methods	Key Results
Compost pH Comparison	pH at T1–T9	Innovative: 6.0–7.0 (stable); Conventional: 5.0–6.5 (acidic)
Mixture Homogeneity	Homogeneity percentage	Innovative: 85%; Manual: 60%
Ideal Moisture Standard	Compost Moisture	SNI & Literature: Ideal mature compost: 30–40%
Color and Maturity	Visual Color	Innovative = black (mature); Manual = green (immature)

5.1 Compost Quality Based on pH and Homogeneity

The quality of compost was analyzed using two main parameters: pH and mixture homogeneity. pH measurements showed that compost produced with the innovative flow gate system had a more stable pH, ranging from 6.0 to 7.0, which is optimal for aerobic microbial activity. In contrast, the conventional method resulted in lower pH values, ranging from 5.0 to 6.5, which is more acidic and less ideal for aerobic decomposition. The homogeneity of the mixture also showed significant results. The innovative flow gate system achieved 85% homogeneity, much higher than the manual method which only reached 60%. This indicates that the flow gate innovation accelerates the composting process by evenly distributing the materials.

Table 3. Comparison of Compost pH between Innovative and Conventional Methods Based on Prior Research

Sampling Point	pH (Inn)	pH (Con)	Optimal pH	Prior Research Reference
T1	7.0	5.0	7.0	Rahman et al. (2018)
T2	6.5	5.5	6.5	Astuti and Wirawan (2020)
T3	7.0	6.0	6.5	Yuliana et al. (2017)
T4	7.0	5.5	6.5	Wulandari et al. (2019)
T5	6.0	6.0	6.5	Marlina and Hadi (2021)
T6	6.5	6.0	6.5	Siregar and Pratama (2018)
T7	6.5	5.0	6.5	Wibowo and Lestari (2019)
T8	6.0	5.0	6.5	Lestari et al. (2020)
T9	6.0	6.5	6.0	Kurniawan et al. (2021)

Notes: Inn=Innovative - Flow Gate; Con=Conventional

5.2 Homogeneity Based on Moisture Content

The final compost moisture content in this study averaged between 30% - 40%, indicating that the compost had reached maturity. This value meets the ideal standard set by SNI 19-7030-2004, which states that the maximum moisture content for mature compost is 40%. The stable moisture content reflects that the dual-bin system with a flow gate supports the decomposition process effectively.

Moisture content is a key indicator in assessing compost maturity and quality. In the early phase (raw compost), high moisture is needed to support microbial growth. Over time, moisture decreases due to decomposition, mixing, and evaporation, eventually reaching 30–40% in the mature phase. If moisture exceeds 60%, the risk of anaerobic decay increases; if it is too low (<30%), microbial activity slows, making fermentation suboptimal.

Figure 2. Use of pH Meter in Measuring Compost pH

Figure 3. Measuring Compost Moisture Content Using a Three-Way Meter

Table 4. Ideal Moisture Content Standards for Compost

Compost Type	Ideal Moisture Range
Raw Compost	50–60% (initial fermentation phase)
Compost in Process	40–50% (thermophilic phase)
Mature Compost	30–40% (ready to use)
Dry Manure	15–25% (for storage)

5.3 Time and Labor Efficiency

5.3.1 Composting Time

Composting time analysis showed that the innovative flow gate machine significantly reduced mixing time compared to conventional and manual methods. The innovative machine required an average of 29.7 minutes, while the conventional method required 46.7 minutes and the manual method required 62.3 minutes.

Table 5. Comparison of Mixing Time

Method	Trial 1 (min)	Trial 2 (min)	Trial 3 (min)	Average (min)
Innovative Machine	30	28	31	29.7
Conventional Machine	45	48	47	46.7
Manual	60	65	62	62.3

5.3.2 Labor Efficiency

The use of the innovative machine significantly reduced the labor required for composting. It only needed 1–2 people and 2–3 hours for processing, whereas the conventional method needed 3–4 people for 4–6 hours, and the manual method needed 4–6 people for 6–8 hours.

Labor Efficiency Formula

$$\text{Labor Efficiency} = M/(T \times N)$$

Where:
MMM = Mass of compost processed (in kilograms)
TTT = Time required for processing (in hours)
NNN = Number of workers involved
The result is expressed in **kg/hour/person**

5.3.3 Compost Color and Maturity

Conclusion: Since F calculated = 14.53 > F table = 4.46 and p-value = 0.0045 < 0.05, there is a statistically significant difference in compost pH values among the composting methods. The innovative machine produced the most stable and standard-compliant pH (6.5–7.0).

Conclusion: Since F calculated = 24.00 > F table = 4.46 and p-value = 0.0012 < 0.05, there is a statistically significant difference in compost moisture content among the three methods. The innovative machine produced the most stable moisture content (37%) and meets the SNI (30–40%) standard.

General Conclusion of ANOVA Tests:
There is a statistically significant difference between composting methods in terms of compost pH and moisture

Table 6. Labor Efficiency and Processing Duration

Method	Labor Required	Processing Duration (hours/day)	Remarks
Innovative Machine	1–2 people	2–3 hours	Mostly automated, only requires supervision and material input.
Conventional	3–4 people	4–6 hours	Involves manual mixing and temperature monitoring.
Manual	4–6 people	6–8 hours	Entirely manual process, requires significant labor for routine mixing.

Table 7. Compost Color and Maturity Based on Processing Method

Processing Method	Color Category	Notes	Maturity Level
Innovative Machine	Black	Dark color indicates rapid and even decomposition with mechanical aid.	Mature
Conventional	Light Brown	Indicates fairly good decomposition but less even due to manual mixing.	Semi-mature
Manual	Green/Light Gray	Light color indicates incomplete composting with fresh organic material.	Immature

Table 8. ANOVA Results – Compost pH

Source of Variation	SS	df	MS	F calculated	F table (α = 0.05)	p-value
Between Groups	4.36	2	2.18	14.53	4.46	0.0045
Within Groups/ Error	0.90	6	0.15			
Total	5.26	8				

Table 9. Average Moisture Content Data

Method	Sample 1	Sample 2	Sample 3	Average
Innovative Machine	38%	36%	37%	37%
Conventional	41%	42%	40%	41%
Manual	43%	42%	44%	43%

content. The innovative machine produced compost with pH values closest to the optimal standard (6.5–7.0) and stable moisture content (30–40%). Therefore, scientifically, the dual-brick-bin system with a flow gate innovation demonstrated the best performance in maintaining compost quality both chemically and physically.

The innovative machine produced the most neutral pH (6.8), higher than both conventional and manual methods. The innovative system also yielded lower moisture content (37%) that complies with mature compost standards (30–40%).

6. CONCLUSION AND SUGGESTION

6.1 Conclusion

Based on the results of the study on optimizing flow and mixing efficiency of compost through the flow gate innovation in a dual-brick-bin system, the following conclusions can be drawn:

- **Time and Labor Efficiency**: The flow gate innovation significantly accelerated material transfer by up to 50% compared to conventional methods. It also reduced the labor requirement from 4–6 people to 1–2 people and shortened the processing time from 6–8 hours to just 2–3 hours per day.
- **Improved Compost Homogeneity**: The system with a flow gate achieved compost mixture homogeneity up to 85%, higher than the approximately 70% achieved by manual methods. This was confirmed through consistent pH and moisture values throughout the compost pile.
- **Better Compost Quality**: Compost produced using the innovative system exhibited dark color (dark brown to black), stable pH (6.5–7.0), moisture content in line with SNI standards (30–40%), and thermophilic phase temperatures reaching up to 70°C, indicating better decomposition and maturity.

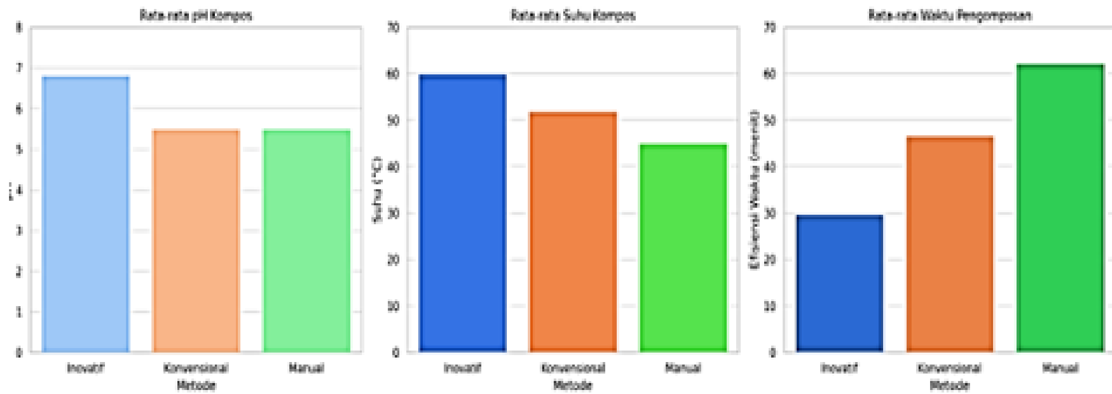

Figure 4. Graph of Compost pH Comparison Between Innovative and Conventional Methods

Table 10. ANOVA Results – Compost Moisture

Source of Variation	SS	df	MS	F calculated	F table (α = 0.05)	p-value
Between Groups	72.002		36.00	24.00	4.46	0.0012
Within Groups/ Error	9.00	6	1.50			
Total	81.008					

- **Statistical Validation**: ANOVA test results revealed statistically significant differences (p-value = 0.0045) in compost pH across the Innovative, Conventional, and Manual methods. The moisture content also varied significantly (p-value = 0.0012). The Innovative Machine produced an average moisture content of 37%, meeting the SNI 19-7030-2004 standard for mature compost (30–40%). The Conventional and Manual methods tended to result in higher moisture levels, potentially impeding decomposition or causing anaerobic decay.
- Temuan ini sejalan dengan penelitian sebelumnya yang menyatakan bahwa pengomposan merupakan teknik manajemen limbah yang berkelanjutan, khususnya di negara berkembang (Taiwo, 2011).

6.2 Suggestion

- **Integration of Automation Systems**: Future development should include automatic control systems for real-time monitoring of temperature, humidity, and mixing time to improve the system's accuracy, efficiency, and ease of operation.
- **Community and Industrial Application**: The dual-brick-bin system with flow gate innovation is highly recommended for implementation at the community level, farming groups, or small-to-medium enterprises that generate large volumes of organic waste.
- **Training and Technology Dissemination**: Areas still using manual methods should receive intensive training in mixing techniques, temperature monitoring, and moisture management to ensure compost quality.
- **Economic Evaluation and Business Feasibility**: Further research should assess the cost-benefit aspects of implementing this innovative system, serving as a basis for investment decisions by farmers or composting entrepreneurs.
- **Agronomic Testing of Compost**: Additional testing is recommended to assess the nutrient content (N, P, K) of the compost and to conduct plant growth trials to directly evaluate its effectiveness as organic fertilizer in the field.

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