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Performance Enhancement of Mixing Impellers Based on Mixture PPM Analysis

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Abstract. *Achieving optimal fertilizer mixing is crucial for farmers, as it directly affects product quality, homogeneity, and overall production efficiency. However, the exact degree of mixing uniformity remains uncertain due to the lack of TDS meters or sensors in the field. This research aims to compare the performance of a novel paddle and PBT-4 impeller while generating empirical data that can serve as a reference for mixing NPK fertilizers. The findings will help farmers to determine the appropriate mixer and optimal mixing duration. The Define-Measure-Analyze-Improve-Control (DMAIC) approach was employed to develop and implement the proposed mixing impellers. Comparative analysis indicates that the novel paddle outperforms the PBT-4 impeller in mixture homogeneity, as evidenced by its lower Coefficient of Variation (COV) of 0.00163 compared to 0.0229. No significant difference was observed in the time required to reach steady ppm or settling time. Ppm is a crucial parameter for assessing mixing uniformity and product quality. While both the Paddle and 4-blade PBT exhibited similar mixing times, the Paddle demonstrated slightly superior performance in achieving uniformity.*
Keywords: *NPK fertilizers; mixing impellers; DMAIC; TDS meters; ppm.*

Type of the Paper: Regular Article.

1. Introduction

In Indonesia's agricultural development, farmers play a pivotal role in driving industry growth. According to data from BPS (Badan Pusat Statistik) [1], the agricultural sector contribution to Indonesia's GDP (Gross Domestic Product) increased steadily from 12.71% in 2019 to 13.28% in 2021. The agricultural sector accounts for 13.28% of Indonesia's GDP and significantly contributes to employment (36%) and taxable income (1.34%). Although agricultural exports comprised only 1.83% of total exports in 2021, the Indonesian government is actively working to increase exports by approximately 4% annually [1,2].

Beyond its contribution to GDP, agriculture is also a major employer. According to BPS [1], as of August 2021, the sector employed 28.33% of Indonesia's workforce, or 37.1 million people. During the COVID-19 pandemic, the sector absorbed workers from industries facing layoffs. In August 2020, the agricultural workforce increased to 29.76% up from 27.53% in 2019. Improvements in the sector are reflected in the rise of the Farmer's Exchange Rate (NTP), a measure of farmers' welfare. The NTP reached 108.34 in December 2021, marking a 1.08% increase from 107.18 in November 2021 [3].

As farmers play a central role in meeting the growing demand for food and sustaining the

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national economy, efficient fertilizer utilization becomes essential. The Indonesian government uses fertilizer subsidies to boost agricultural productivity and improve farmers' welfare. These subsidies cover both inorganic and organic fertilizers. However, the utilization pattern among farmers is heavily skewed toward inorganic fertilizers, with 86.5% of Indonesian farmers opting for them [4].

Fertilizers are crucial for enhancing soil fertility and optimizing crop yields. Effective nutrient management plays a key role in modern agriculture, as it significantly influences crop growth, soil fertility, and sustainable food production. Proper management of nutrients such as nitrogen, phosphorus, and potassium is essential for maintaining plant health, achieving high crop yields, and ensuring environmental stewardship. Nutrient imbalances or deficiencies can lead to decreased crop productivity, increased vulnerability to diseases, and negative environmental impacts, such as water pollution from nutrient runoff [5]. Recognizing its importance, the fertilizer mixing process is a critical link in the agricultural value chain. The efficiency of this process directly affects the quality and effectiveness of the fertilizers that farmers rely on.

While significant progress has been made in understanding the role of mixing in agricultural and industrial processes, critical gaps remain in optimizing mixing techniques for fertilizer production, particularly within Indonesia's agricultural sector. Existing studies have primarily focused on general mixing principles, impeller design, and computational fluid dynamics, often in industrial contexts unrelated to agriculture. Few have addressed the specific requirements of nutrient mixing for fertilizers, particularly the uniformity of nitrogen-phosphate-potassium (NPK) blends, which are crucial for soil fertility and crop productivity [5,6]. Furthermore, the practical application of mixing systems in developing countries, such as Indonesia, remains underexplored, particularly concerning locally available equipment and sensors. This research addresses these gaps by evaluating the performance of a newly designed paddle and PBT-4 impeller for mixing NPK fertilizer in a 500-liter tank, using accessible TDS sensors to measure uniformity [7–9]. By bridging the gap between theoretical insights and practical applications, the study aims to enhance fertilizer mixing efficiency, thereby contributing to sustainable agricultural development.

Mixing is the process of combining ingredients—solid, liquid, gas, or a combination of these—to obtain a homogenous mixture [10]. Various mixing techniques using stirred tanks have been designed to meet diverse production and processing needs, with these tanks employed in 25% of all process industry operations as adaptable mixing tools for a wide range of applications [11]. Ascanio [7] reviewed experimental techniques used over the past 50 years for measuring mixing time in stirred vessels. Various methods have been developed for this purpose, categorized as non-intrusive and intrusive based on their impact on flow disturbances. Additionally, these methods can be classified as direct or indirect measurements, depending on the type of data they provide.

The choice of technique for measuring mixing times in agitated tanks depends on factors such as accuracy, reproducibility, suitability, cost, sampling speed, type of data, and processing time, as different techniques offer distinct types of information [7]. In agricultural contexts, mixing configurations are applied in various operations, including the formulation of concentrations for agricultural chemicals, the adjustment of nutrient levels in fertilizer tanks, the combination of substances, and the processing of agricultural products.

A study by Jiang et al. [12] examines how the position of the agitator within a stirred tank influences particle concentration distribution and finds that adjusting the agitator's height from the tank bottom significantly affects particle uniformity. Efficient fluid mechanical agitation is crucial in various industrial settings to achieve optimal mixing and effective heat transfer in tanks and vessels. Mechanical agitation and mixing are fundamental to many production processes, ensuring product quality, safety, and consistency [13]. Stirrers enhance the interaction among particles and prevent uneven mixtures, particularly when mixing soluble solids [14]. Variations in mixing quality are often caused by the complex turbulence generated by impellers, which depends on their design, geometry, rotational speed, and the properties of the fluid being mixed (mxdprocess.com). Different impeller types, such as axial or radial flow, generate specific flow patterns and shear forces that influence circulation and turbulence effects, making them suitable for various applications (framatomebhr.com). Understanding these dynamics is essential for optimizing mixing efficiency and ensuring consistent product quality. Previous research on mixing quality in stirred tanks has shown that the conventional approach to achieving optimal mixing involves increasing the impeller's rotational speed to minimize stagnant regions [15]. Additionally, combining mean age theory with fully transient techniques can provide valuable insights into mixing quality within the tank [11].

Flow velocities within stirred vessels are recognized as turbulent and complex, accurate measurement challenging. This complexity complicates the achievement of uniformity in mixing processes. Ensuring consistent concentrations in blended products is crucial for the efficient and cost-effective use of high-value chemicals, fertilizers, and other mixing agents. Therefore, it is essential to select equipment that generates adequate turbulence and flow within the mixing vessel.

Comprehensive studies are necessary to evaluate mixing efficiency and accurately predict the overall performance of these systems. Research has shown that the effectiveness of mixing is influenced by factors such as mixing time, impeller type, the number and size of blades, rotational speed, and vessel configuration [8]. Additionally, the effectiveness of mixing depends on factors such as the state of mixed phases, temperature, viscosity and density of liquids, mutual solubility of mixed fluids, type of stirrer, and, critically, the shape of the impeller [6].

In large-scale mixing operations, it is crucial for stirrers and the entire agitation system to promote rapid substance movement and generate significant turbulence. This complexity makes analyzing the entire mixing process in large containers challenging and often impractical through experimental methods. Recent advancements in computational fluid dynamics (CFD) have enabled detailed studies of various impeller designs, highlighting their significant impact on mixing performance [8]. Additionally, the development of fractal impellers shows promise in reducing energy consumption while maintaining effective mixing by altering flow patterns to enhance turbulence [9].

This research evaluates the performance of a new paddle and PBT-4 impeller design for mixing nitrogen-phosphate-kalium (NPK) 16-16-16 fertilizer in a 500-liter tank. It compares mixing time and uniformity based on parts per million (ppm) readings from total dissolved solids (TDS) sensors placed at three positions in the tank. The tank and TDS sensors used are commonly available in Indonesian markets.

2. Materials and Methods

This research adopts the DMAIC (Define, Measure, Analyze, Improve, Control) approach as the framework for investigating and enhancing the performance of mixing impellers, aiming for methodological precision and systematic inquiry. The DMAIC methodology, grounded in process improvement principles, provides a structured pathway to systematically address challenges, optimize processes, and drive sustainable improvements.

DMAIC is commonly associated with Six Sigma, a set of techniques and tools for process improvement and quality management. According to Montgomery and Woodall [16], the core focus of Six Sigma is minimizing variability in product attributes within specified targets, thereby making defects improbable. If defects occur, they are expected to be limited to 3.4 defects per million opportunities. In the Define phase, the research goals, scope, and deliverables are clearly outlined. This phase involves understanding the problem, conducting a literature review, and establishing a conceptual model. The Measure phase involves quantifying and assessing the current state of the mixing impeller using relevant data. During the Analyze stage, the data are analyzed to identify the root causes of problems and opportunities for improvement. In the Improve stage, the prototype is developed and implemented. In addition, the performance of both mixing impellers is compared to verify the achievement of the desired improvements. The final phase, the Control phase, focuses on ensuring the sustained success of the improvements by preparing a preliminary checklist for the user. Desai and Pandit [17] summarized the entire DMAIC framework, tools, and actions that can be utilized as quality improvement tools for casting defects in foundries. The DMAIC approach was utilized by Liang et al. [18] as a research framework to improve daily total completed shipments in an Indonesian car spare parts manufacturer using system dynamics simulation. The recently revamped inventory system successfully reduced the backlog of orders and increased the daily total of completed shipments. In an applied empirical study, Lean Six Sigma and DMAIC methodologies were utilized to reduce defects in a car parts manufacturing process. The study identified key defects and factors contributing to defective parts in the die-casting and machining processes. The implemented solutions successfully reduced defect rates from persistently high levels to acceptable ones. Consequently, the sigma level consistently increased from 3.4σ to 4σ [19]. Additionally, a standardized operating procedure for system operation was developed and provided to the company for future reference. According to Giannetti et al. [20], the principal factor driving process enhancement in the Six Sigma methodology is the generation of knowledge.

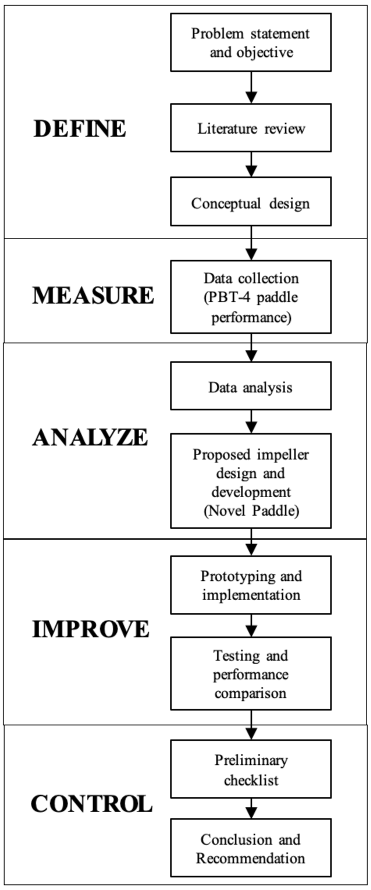

Fig. 1. Proposed Research Framework

Fig. 1 illustrates the proposed research framework for improving the performance of mixing impellers. The flowchart in Fig. 1 outlines a structured approach based on the DMAIC methodology (Define, Measure, Analyze, Improve, Control), commonly used in Six Sigma and other process improvement frameworks. Each phase is designed to guide the project systematically from problem identification to solution implementation and control.

In the Define phase, the process begins with a clear identification of the problem and the project objectives, followed by a literature review to assess existing knowledge, methods, and practices. Finally, a conceptual design is developed as an initial framework to address the identified issues.

The Measure phase focuses on data collection and analysis. Performance data for the PBT-4 paddle is gathered to assess the current system state, followed by analysis to identify gaps, inefficiencies, or areas for improvement, which guide the next phase.

In the Analyze phase, the data analysis findings are used to propose a new impeller design, the Novel Paddle. This phase is critical as it transitions from problem diagnosis to the formulation of a potential solution.

The Improve phase involves prototyping and implementing the proposed solution. The new design is tested, and its performance is compared to the existing system to ensure effectiveness and measurable improvements.

The Control phase ensures sustained improvements through a preliminary checklist to maintain consistency and monitor performance. The project concludes with a summary of findings, recommendations for further actions, and an evaluation of the solution's success.

This structured flow ensures a data-driven, systematic approach focused on continuous improvement. Each phase builds on the previous, providing a comprehensive framework for problem-solving and solution implementation.

3. Results and Discussion

This section offers a concise yet thorough exploration of the design, development, and analysis processes for mixing impellers, supported by relevant statistical analyses. The emphasis is on clarifying the key aspects involved in crafting these essential components for diverse applications. Statistical tools, such as regression analysis, were used to validate sensor performance by examining the relationship between volume fraction (VF), concentration (C), and the averaged ppm levels across different layers (from top to bottom). Additionally, line graphs were employed to analyze the relationship between time and ppm levels in various NPK granular masses. These methods provided deeper insights into the interaction between critical design parameters and operational conditions, facilitating the optimization of impeller configurations to enhance performance.

3.1. PBT-4 paddle

According to Sayyad et al. [21], mixing efficiency depends on impeller design, including its diameter. A commonly used design is the four-blade pitched blade turbine (PBT), which is selected for small concentration nutrition mixing and requires only a smaller agitator [22,23].

The testing simulated the real-life applications by varying NPK and water proportions up to a maximum of 20 gr/L. The mixer was powered by a 0.5 HP 1400 RPM motor with a worm gear reduction of approximately 1:10, providing sufficient torque for mixing. This resulted in a final rotational speed of 140 RPM. The tank maintained a constant volume of 500-liter of NPK solids, portioned into 2.5 kg (5gr/L), 5 kg (10gr/L), 7.5 kg (15gr/L), and 10 kg (20gr/L). The impeller rotated for 5 minutes, with data collected at 30-second intervals.

Fig. 2 illustrates the mixing impellers design utilized in this research, while Fig. 3 and Fig. 4 present the fundamental dimensional parameters for their development.

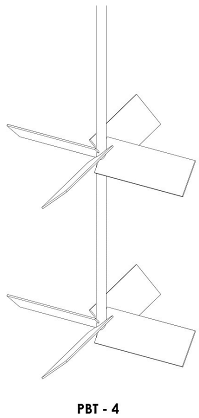

Fig. 2. Impeller Design (PBT-4)

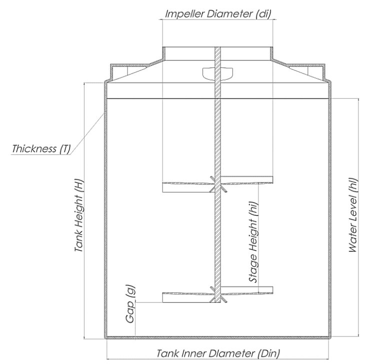

Fig. 3. Parameters of the Tank

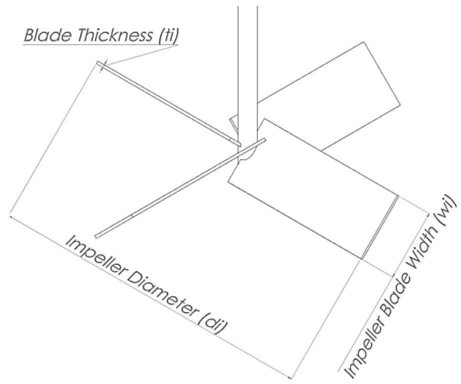

Fig. 4. Parameters of the Impeller (PBT-4)

The blade design variables are calculated based on the main tank, with the resulting values optimized for the mixing process [24].

Impeller diameter (d_i*) = 360 mm

Blade width (w_i) = 72 mm

Blade thickness (t_i) = 3 mm

Water level (h_L) = 800 mm

Number of blades (n_i) = ~2 blades

Stage height (h_i) = 360 mm

Gap (g) = 114 mm

*Due to the constraint of the tank's top opening, the impeller's diameter is maximized to fit within the opening while maintaining an optimal d_i/D_{in} ratio of ¼–½ [8].

3.2. Proposed impeller design

Another impeller was developed to improve upon the previous impeller design and serve as a comparison to the existing design, as shown in Fig. 5. The design modifies the PBT-2 paddle (with two blades) by incorporating a square hollow stainless-steel bar for structural support, addressing concerns about the older design's instability in high-viscosity mixtures. All design parameters remain the same as those of the PBT-4 design.

The proposed impeller, referred to as “Paddle”, incorporates square hollow bars around the blades to increase strength while retaining the advantages of a paddle-type impeller. It features two stacked blades with opposing inward axial flow. According to Satjaritanun and Zenyuk [25], contra-rotating blades provide sufficient agitation in a baffle-less tank at a low-speed RPM (in this case, ~140 RPM). While their study examined the PBT impeller design, no data available for the Paddle impeller, as it is a novel design.

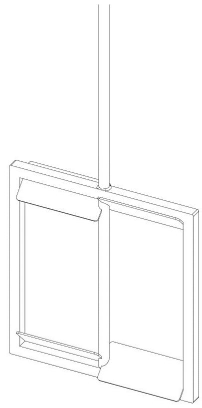

Fig. 5. Parameters of the Impeller

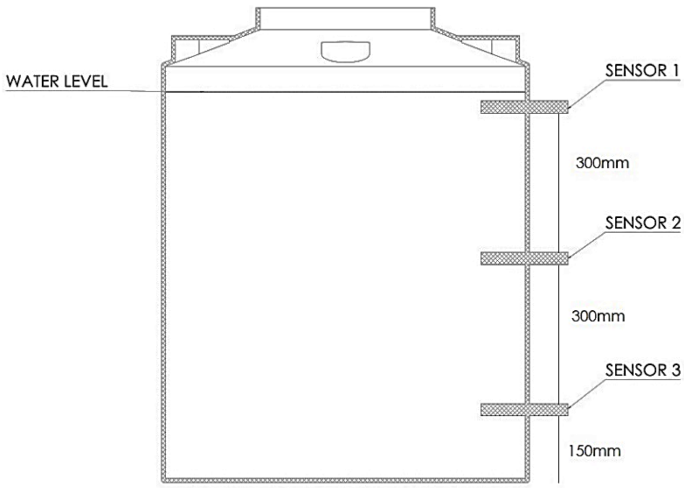

Fig. 6. Attached EC Sensors at HDPE Tank

3.3. Mixing test in an HDPE tank

The tank is a standard 500-liter high-density polyethylene (HDPE) water storage tank without baffles. The test aims to evaluate its performance in a typical water storage tank, with the impeller design minimizing the need for baffles [25]. No major modifications were done to the tank. The TDS sensors are generic portable electric conductivity (EC) sensors, which can be scaled into the ppm sensor. EC sensors were chosen for their proven ability to assess mixing uniformness [26]. These sensors were mounted at three locations on the tank's side by drilling holes in the wall and securing them with sealant.

Positioning at varying heights, they accurately assess the mixing characteristic, as the impeller design introduces axial flow inside the tank. Fig. 6 illustrates the placement of EC sensors on the HDPE tank.

3.4. Pre-testing checklist

To maintain a controlled testing environment, a pre-testing checklist was made to ensure that all tests were conducted under identical conditions, and minimizing the influence of external factors on the results. Table 1 presents the pre-testing checklist used:

Table 1. Pre-Testing Checklist

	PRE-TESTING CHECKLIST	No: Name: Date:
No.	**Name**	**Check**
1	Move Tank into a Designated Secure Area	
2	Check and Take Notes of Ambient Temperature	
3	Clean and Drain Tank	
4	Check for Piping Leaks	
5	Check for Sensor Leaks	
6	Check for Mixer Structural Integrity	
7	Check for Electrical Components	
8	Calibrate Sensor to Water ppm (Target: 100-200)	
9	Validate RPM of the Motor	

3.5. Sensor validation

A standard numerical method, such as a linear regression model [26], can be used to validate the sensor by determining the relationship between the volume fraction (VF), concentration (C), and the average ppm level (from top to bottom).

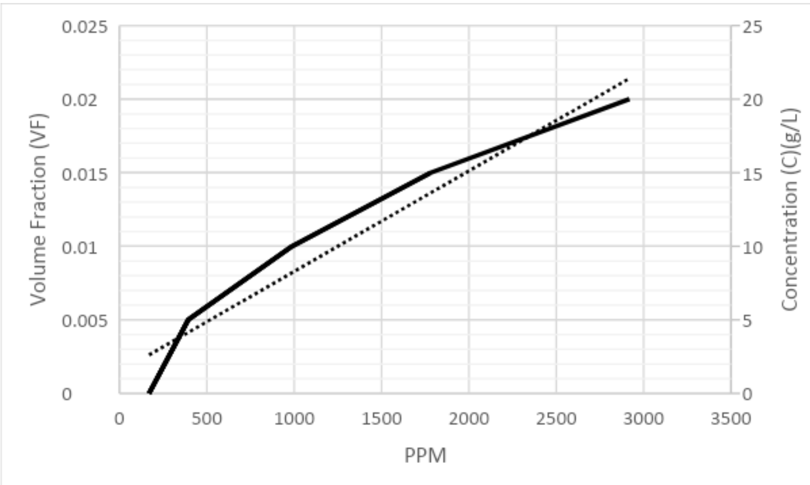

Fig. 7. The Relationship of VF, C, and ppm

Fig. 7 illustrates the relationship between VF, C, and ppm. The linear regression model describes the relationship as mentioned in Eq. (1).

$$VF = 0.0068 \cdot ppm + 1.4538 \quad (1)$$

with a fitting degree of 0.9415, which means around there is a 5.85% error for the system model.

3.6. Testing results

In assessing the performance of the two types of mixing impeller system, a critical analysis of mixing efficiency and settling time provides valuable insights into their effectiveness. Mixing efficiency, reflecting the system's ability to uniformly disperse components, plays a pivotal role in determining the overall quality of the mixture. In contrast, settling time is a key metric that measures the time required for suspended particles to settle after mixing.

The PBT-4 impeller demonstrates unique characteristics regarding mixing efficiency and settling time, making it suitable for specific applications. Quantitatively, the PBT-4 impeller achieves a critical radius of vortex zones radius (r_c^*) of 0.18R, smaller than that of the Rushton turbine ($rc*$=0.28R) and the concave-disc blade turbine (r_c^*=0.24R) [27]. This indicates that the PBT-4 impeller delivers energy more locally, focusing on smaller regions within the tank. Additionally, its dimensionless maximum velocity ($u_{\max}/u_{\text{tip}}$) is 0.36, lower than 0.57 for the Rushton turbine and 0.40 for the CD-6 [27]. While these values highlight its relatively weaker mixing intensity, they also reflect its energy efficiency, as evidenced by its power number (Np) of 0.76, significantly lower than the Rushton turbine (N_p=1.38) and the CD-6 (N_p=1.30) [27,28].

However, the reduced mixing intensity of the PBT-4 affects settling time, particularly in unbaffled tanks where axial velocities are weaker. Axial flow, essential for suspending particles, is less pronounced with the PBT-4, contributing to longer settling times. Research indicates that settling times in unbaffled tanks can be two to three times longer than in baffled configurations due to the absence of strong axial currents needed for particle resuspension [27]. Furthermore, the PBT-4's smaller critical radius confines its effectiveness to localized zones, potentially leaving distant areas of the tank with inadequate mixing energy [27]. In summary, the PBT-4 impeller combines energy efficiency with moderate mixing performance, as evidenced by its low power number and limited critical radius. While it is a cost-effective solution for low-viscosity fluids or processes that do not require high-intensity mixing, its longer settling times may pose challenges in systems demanding rapid and uniform particle suspension [27,28].

Fig. 8 illustrates the relationship between mixing time and ppm level of fertilizers with the various NPK granules' masses. The 'Initial' value in Fig. 8 describes the ppm level of the clean water, and the '0' point describes the PPM level after the addition of NPK granules into the tank. Referring to the actual value of the dataset, both impellers cannot evenly mix the particulates inside the mixing tank, which is caused by incorrect parameters for the impeller design. The three sensors always indicate significantly different PPM levels, ranging from the highest ppm number on the bottom-most sensor to the lowest number on the topmost sensor. For the 10kg testing, the bottom TDS sensors indicate a larger error rate. This is due to the display for the ppm level capped at 4 digits, resulting in a different scaling of the sensor, as it is only showing in tens of parts per thousand (ppt).

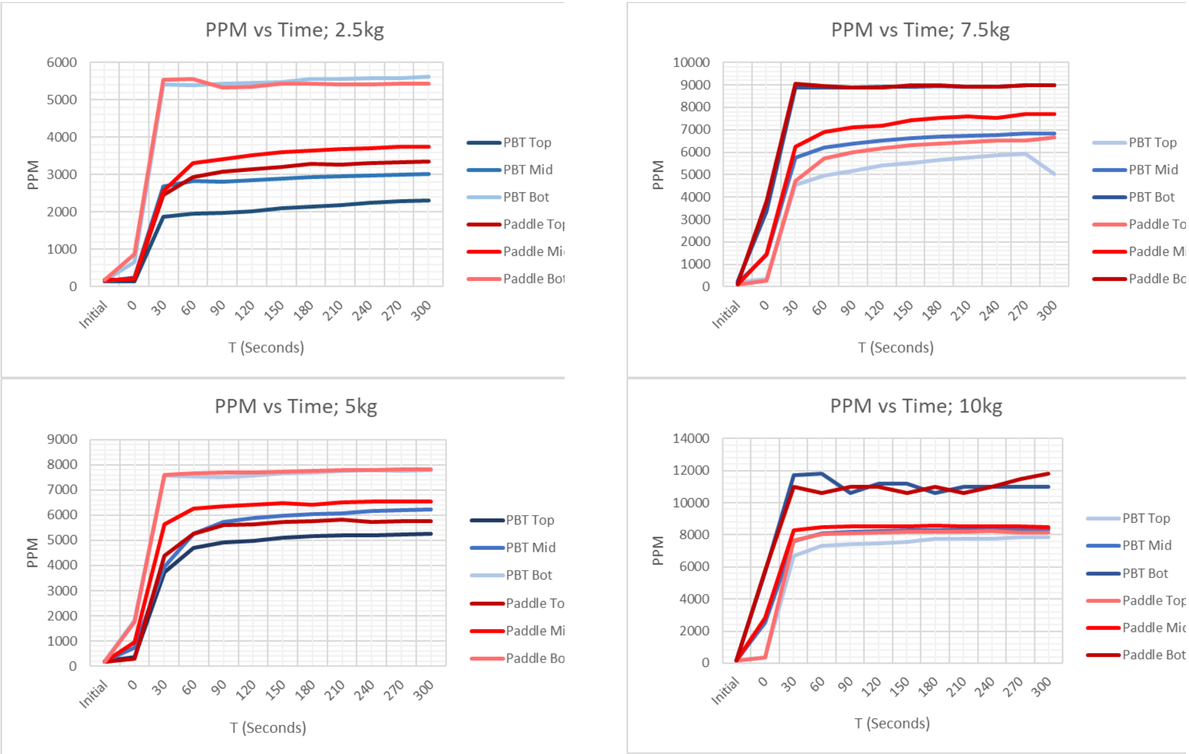

Fig. 8. Relationship between Time and ppm in Various NPK Granules' Masses

Table 2. Estimated COV with Various NPK Granules' Masses

2.5 kg					
PBT			PADDLE		
Top	*Middle*	*Bottom*	*Top*	*Middle*	*Bottom*
0.052847	0.022905	0.011733	0.028118	0.029642	0.006492
	AVERAGE	**0.029162**		**AVERAGE**	**0.021417**

5 kg					
PBT			PADDLE		
Top	*Middle*	*Bottom*	*Top*	*Middle*	*Bottom*
0.022277	0.026929	0.012141	0.011298	0.010243	0.006182
	AVERAGE	**0.020449**		**AVERAGE**	**0.009241**

7.5 kg					
PBT			PADDLE		
Top	*Middle*	*Bottom*	*Top*	*Middle*	*Bottom*
0.053939	0.021386	0.003842	0.030641	0.026953	0.004438
	AVERAGE	**0.026389**		**AVERAGE**	**0.020677**

10 kg					
PBT			PADDLE		
Top	*Middle*	*Bottom*	*Top*	*Middle*	*Bottom*
0.021107	0.005782	0.019904	0.003956	0.002419	0.034699
	AVERAGE	**0.015598**		**AVERAGE**	**0.013691**

Interestingly, Fig. 8 reveals that the paddle has consistently higher ppm numbers across all data takings. This resulted from better mixing, as more particulates are produced inside the mixing tank during the breaking down of the NPK granules. The primary variable for assessing mixing uniformity is ppm. This also can be confirmed by checking for coefficient of variation (COV) of the two systems [26]. COV is defined in Eq. (2).

$$COV = \frac{\sigma_{population}}{\mu_{population}} \quad (2)$$

where $\sigma_{population}$ is the standard deviation of the population and $\mu_{population}$ is the mean of the population

Table 2 shows the data calculated for the COV values after T>60 s or after 1 minute of mixing with various NPK granules' masses.

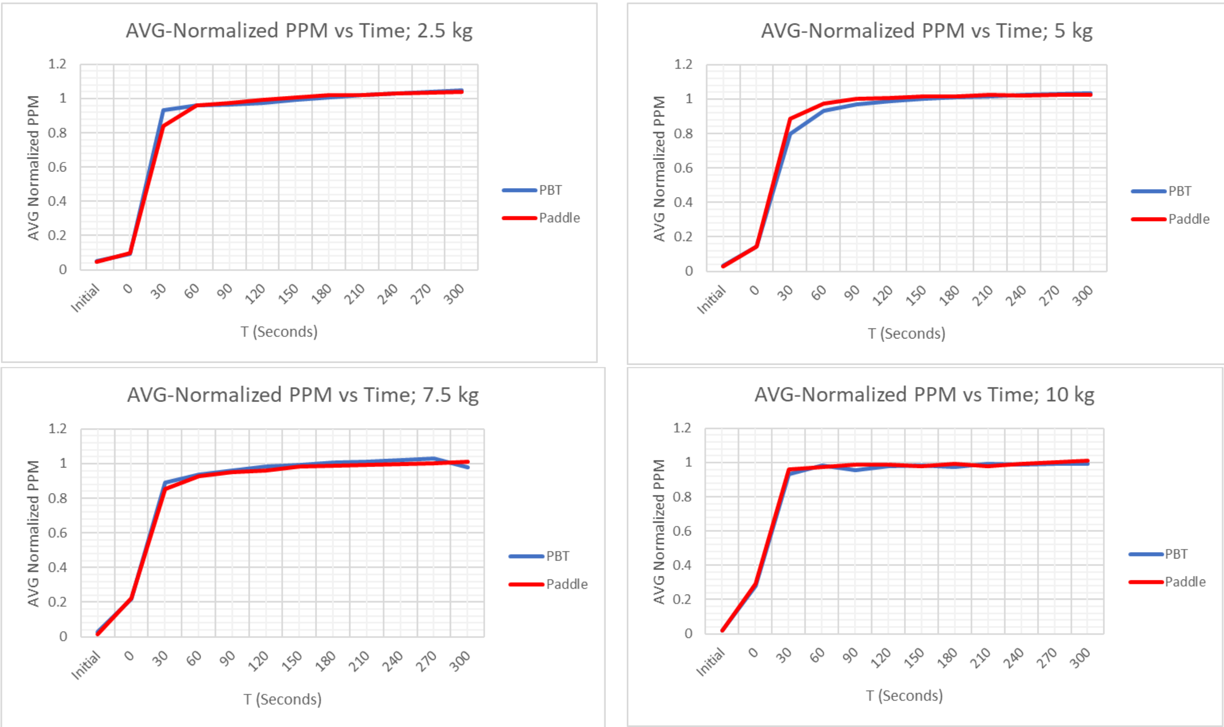

Fig. 9. AVG-Normalized ppm vs Time for Different Masses

After comparison, the results indicate that the Paddle performs better, compared to PBT's, with a 26.56% improvement for 2.5 kg mixing, 54.81% for 5 kg mixing, 21.64% for 7.5 kg mixing, and 12.22% for the 10 kg mixing.

The values are then normalized and averaged to evaluate the time needed to reach the settling time. The mixing settling time is not significant, as both impellers are required at approximately the same time to mix the granules.

Fig. 9 indicates that the average normalized ppm with the same mixing time by various granules masses. A system demonstrating high mixing efficiency ensures that the constituents are thoroughly integrated, promoting homogeneity in the final product. A shorter settling time indicates a more efficient system, as it signifies a rapid and stable suspension of particles. The interplay between mixing efficiency and settling time is integral, as an optimally performing system should not only achieve a well-mixed product but also facilitate minimal settling. This comprehensive approach to performance evaluation provides a nuanced understanding of the mixing systems, supporting the selection and optimization of processes tailored to specific industrial or scientific requirements.

4. Conclusions

The monitoring of mixing uniformity is a critical aspect of ensuring product quality and consistency. The ppm serves as a valuable variable for quantifying the uniform distribution of components within a mixture. The comparison between the novel Paddle and the well-established 4-blade PBT reveals intriguing insights into their performance. Notably, the Paddle shows a slightly superior capability in achieving mixing uniformity as compared to that of the widely known 4-blade PBT. This suggests that the Paddle offers enhanced homogeneity, leading to a more uniformly blended end-product. Interestingly, despite the observed differences in mixing uniformness, there is no discernible distinction in the efficient mixing time between the two impeller types. This finding implies that both impellers exhibit similar efficiency in terms of the time required to achieve optimal mixing, even as their approaches to uniformity vary.

Building upon these qualitative observations, quantitative analysis further substantiates the Paddle impeller's advantages. Coefficient of Variation (COV) calculations indicated that the Paddle impeller achieved consistently lower values compared to the PBT-4, with improvements ranging from 12.22% to 54.81% across different NPK granular masses. This confirms the Paddle's improved ability to produce a homogeneous mixture. Regression analysis validated the reliability of the utilized sensor data, with a high fitting degree (R^2=0.9415), highlighting the robustness of the ppm as an indicator of mixing uniformity. Additionally, normalized ppm data illustrated that the Paddle impeller consistently achieved higher ppm values within the same duration, highlighting its superior mixing efficiency.

These findings collectively indicate that the novel Paddle design achieves better mixing uniformity and matches the PBT-4 in terms of mixing time efficiency. Its adoption in fertilizer mixing processes significantly improves nutrient distribution, directly benefiting agricultural productivity. Future research should investigate these designs under varied operating conditions and explore advanced simulation methods to deepen our understanding of mixing dynamics.

Abbreviations

Not applicable.

Data availability statement

Data will be shared upon request by the readers.

CRediT authorship contribution statement

Aditya Tirta Pratama: Conceptualization, Methodology, Formal analysis, Validation, Visualization, Writing – original draft, Writing – review and editing. **Gunawan Zuardi**: Data curation, Supervision, Funding acquisition, Investigation, Project administration, Resources.

Declaration of Competing Interest

The authors of this manuscript declare no conflict of interest or competing interest.

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References

[1] Badan Pusat Statistik. Indonesia's Economic Growth Rate. Berita Resmi Statistik No 14/02/Th XXV 2022:143–51. Available from: https://www.bps.go.id/id/pressrelease/2022/02/07/1911/ekonomi-indonesia-triwulan-iv-2021-tumbuh-5-02-persen--y-on-y-.html

[2] Fadhlan Musyaffa N, Radi Myarta L, Kusuma Paksi A, Dian Iswari R. The Agricultural Sector in Indonesia Amidst COVID-19: Crisis or Opportunity? E3S Web of Conferences 2023;444:02054. https://doi.org/10.1051/e3sconf/202344402054.

[3] Wahyuni AT, Hariyanti D. Determination of the Growth Rate of Gross Domestic Regional Product (GDRP) of the Agricultural Sector in Indonesia, Period 2012 – 2021. International Conference on Entrepreneurship, Leadership and Business Innovation (ICELBI 2022), 2023, p. 176–84. https://doi.org/10.2991/978-94-6463-350-4_17.

[4] Setiono DA. Baru 13,5 Persen Petani Indonesia Gunakan Pupuk Organik 2019. Available from: https://beritajatim.com/ekbis/baru-135-persen-petani-indonesia-gunakan-pupuk-organik/

[5] Raza I, Zubair M, Zaib M, Khalil MH, Haidar A, Sikandar A, et al. Precision nutrient application techniques to improve soil fertility and crop yield: A review with future prospect. International Research Journal of Educational and Tecnology 2023;5. Available from: https://www.irjweb.com/Precision Nutrient Application Techniques to Improve Soil Fertility and Crop Yield A Review with Future Prospect.pdf

[6] Jaszczur M, Młynarczykowska A. A General Review of the Current Development of Mechanically Agitated Vessels. Processes 2020;8:982. https://doi.org/10.3390/pr8080982.

[7] Ascanio G. Mixing time in stirred vessels: A review of experimental techniques. Chinese Journal of Chemical Engineering 2015;23:1065–76. https://doi.org/10.1016/j.cjche.2014.10.022.

[8] Torotwa I, Ji C. A Study of the Mixing Performance of Different Impeller Designs in Stirred Vessels Using Computational Fluid Dynamics. Designs 2018;2:10. https://doi.org/10.3390/designs2010010.

[9] Basbug S, Papadakis G, Vassilicos JC. Reduced energy consumption in stirred vessels by means of fractal impellers. ArXiv Preprint ArXiv:170701730 2017. https://doi.org/https://doi.org/10.48550/arXiv.1707.01730.

[10] Premi M, Sharma V. Mixing and Forming. Agro-Processing and Food Engineering, Singapore: Springer Singapore; 2022, p. 253–305. https://doi.org/10.1007/978-981-16-7289-7_7.

[11] Wu M, Jurtz N, Hohl L, Kraume M. Multi-impeller mixing performance prediction in stirred tanks using mean age theory approach. AIChE Journal 2024;70:e18247. https://doi.org/10.1002/aic.18247.

[12] Jiang H, Yuan S, Liu H, Li W, Zhou X. Numerical analysis and optimization of key parts in the stirred tank based on solid-liquid flow field. Science Progress 2022;105:00368504211067200. https://doi.org/10.1177/00368504211067200.
[13] Mokhefi A. Hydrodynamic and thermal performance analysis of an inclined anchor impeller designed for yield stress food mixing applications. Food and Bioproducts Processing 2024;143:255–70. https://doi.org/10.1016/j.fbp.2023.12.006.
[14] Eggl MF, Schmid PJ. Mixing by stirring: Optimizing shapes and strategies. Phys Rev Fluids 2022;7:73904. https://doi.org/10.1103/PhysRevFluids.7.073904.
[15] Gu D, Yan L, Xu H. Modifications in impeller blades for high efficiency mixing of pseudoplastic fluid in a stirred tank. International Journal of Chemical Reactor Engineering 2024. https://doi.org/10.1515/ijcre-2023-0235.
[16] Montgomery DC, Woodall WH. An Overview of Six Sigma. International Statistical Review 2008;76:329–46. https://doi.org/10.1111/j.1751-5823.2008.00061.x.
[17] Desai EPP, Pandit EHC. Quality Improvement Tools for Casting Defects in Foundry. International Journal of Engineering Research and Applications 2023;13:130–4. https://doi.org/10.9790/9622-1306130134.
[18] Liang S, Pratama AT, Sudarto S. Improving Daily Total Complete Shipment by Using System Dynamics Simulation in an Indonesian Car Spare Parts Manufacturer. Industrial Engineering & Management Systems 2022;21:74–84. https://doi.org/10.7232/iems.2022.21.1.074.
[19] Condé GCP, Oprime PC, Pimenta ML, Sordan JE, Bueno CR. Defect reduction using DMAIC and Lean Six Sigma: A case study in a manufacturing car parts supplier. International Journal of Quality \& Reliability Management 2023. https://doi.org/10.1108/IJQRM-05-2022-0157.
[20] Giannetti C, Ransing RS, Ransing MR, Bould DC, Gethin DT, Sienz J. Knowledge management and knowledge discovery for process improvement and sustainable manufacturing: a foundry case study. Sustainable Design and Manufacturing 2014:254–66. Available from: http://nimbusvault.net/publications/koala/inimpact/papers/sdm14-020.pdf
[21] Sayyad FG, Sharma HK, Kumar N. Cleaning and Separation. Agro-Processing and Food Engineering, Singapore: Springer Singapore; 2022, p. 307–52. https://doi.org/10.1007/978-981-16-7289-7_8.
[22] Ceres D, Jirout T, Rieger F. Pitched Blade Turbine Efficiency at Particle Suspension. Acta Polytechnica 2010;50. https://doi.org/10.14311/1281.
[23] Kresta SM, Wood PE. The flow field produced by a pitched blade turbine: Characterization of the turbulence and estimation of the dissipation rate. Chemical Engineering Science 1993;48:1761–74. https://doi.org/10.1016/0009-2509(93)80346-R.
[24] Kumar A. Design Calculations of Pitch Blade Turbine 2020. Available from: https://www.pharmacalculations.com/2020/11/design-calculations-of-pitch-blade.html
[25] Satjaritanun P, Zenyuk I V. Water management strategies for PGM-free catalyst layers for polymer electrolyte fuel cells. Current Opinion in Electrochemistry 2021;25:100622. https://doi.org/10.1016/j.coelec.2020.08.004.
[26] Sun B, Lu Y, Liu Q, Fang H, Zhang C, Zhang J. Experimental and Numerical Analyses on Mixing Uniformity of Water and Saline in Pipe Flow. Water 2020;12:2281. https://doi.org/10.3390/w12082281.
[27] Li L, Xu B. Numerical analysis of hydrodynamics characteristics in a top-covered unbaffled stirred tank. Chemical Papers 2021;75:5873–84. https://doi.org/10.1007/s11696-021-01767-9.
[28] Liu B, Zhang Y, Chen M, Li P, Jin Z. Power consumption and flow field characteristics of a coaxial mixer with a double inner impeller. Chinese Journal of Chemical Engineering 2015;23:1–6. https://doi.org/10.1016/j.cjche.2013.09.001.