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Comparison of Erosive Wear on Composite and Metallic Propellers in Slurry

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***Abstract* -** The aim of this study was to investigate the influence of material, geometry, and particle concentration on the wear behaviour of propellers. Particular attention was given to the performance of a modified polyamide material called "Physinit" in comparison to stainless steel. Four test series were carried out using a half factorial design of experiments without repetition. The propellers were rotated in an aqueous slurry containing silicon carbide particles at a constant speed of 1493 rpm. The varied factors included propeller material (stainless steel vs. polyamide), geometry (Phantom vs. three-blade), and particle concentration (80 g/l vs. 200 g/l). The primary measured parameters were relative mass loss and change in diameter. Stainless steel showed higher mass loss and greater diameter reduction compared to the Physinit material. Increasing particle concentration led to increased wear. Wear rates were higher for stainless steel across both geometries. Diameter reduction in stainless steel occurred continuously, while Physinit exhibited delayed and lower reduction. Geometry had a noticeable effect on the uniformity of wear, though its overall influence was less pronounced than that of the material. The experimental data indicate that Physinit demonstrates a distinctly different wear behaviour under abrasive conditions compared to stainless steel. Under the given test conditions, the wear rate of the Physinit propeller was significantly lower than that of the stainless-steel propeller.

***Keywords*:** erosive wear, propeller materials, Physinit, wear resistance, slurry, silicon carbide, abrasive mixing

1. Introduction

Propeller-based mixing systems are used in a wide range of industrial applications involving abrasive media. Typical fields of use include biogas plants, flue gas desulfurization (FGD) systems, and drilling mud circulation units [1], [2], [3], [4]. In these environments, the mixing task often involves the continuous suspension and homogenization of solid-laden fluids, subjecting the rotating components to high mechanical and erosive loads [1], [3], [5], [6], [7].

One of the primary limiting factors for the operational life of mixer propellers in such applications is erosive wear [8]. Wear is defined as the progressive loss of material from solid surfaces due to mechanical or chemical interaction with other solids, liquids, or gases [3]. In abrasive slurry conditions, this loss is typically caused by the impact and flow of hard particles across the propeller surface and therefore called erosive wear [3], [8]. The resulting material degradation affects both the structural integrity and the hydraulic performance of the mixing device [3], [8].

Understanding wear behaviour through targeted experimental testing is essential for evaluating the expected lifetime and long-term functionality of propellers under defined conditions [8], [9]. The failure of a worn-out propeller during operation can lead to unexpected downtime and costly maintenance for plant operators. Improving the service life of such components, therefore, offers significant economic advantages and supports more reliable system operation [3].

The aim of this study is to investigate the influence of three key factors on the wear behaviour of submersible mixer propellers: the material composition, the blade geometry, and the concentration of abrasive particles in the fluid. Specifically, a modified polyamide material (Physinit) is compared with conventional stainless steel (1.4301). In addition, a two-blade Phantom geometry is evaluated against a standard three-blade axial-flow propeller. Finally, the tests were performed using two defined silicon carbide particle concentrations to study the impact of slurry composition on wear performance.

This systematic investigation is intended to provide comparative insight into the wear resistance of different material and design choices, forming a basis for future optimization of propeller configurations in abrasive mixing applications.

2. Materials and Methods

The experimental investigation was carried out using a slurry erosion test bench specifically designed for wear testing of model propellers in abrasive fluid environments. The slurry pot tester is commonly used for wear tests [9]. The test setup consisted of an open head plastic drum containing 40 l of water, which was equipped with a clamping ring lid and reinforced by four vertical baffles (see Fig. 1). The baffles inside the test vessel were implemented to prevent vortex formation and to promote turbulent flow conditions, especially at lower rotational speeds [10], [11], [12], [13], [14]. The baffles were designed after norm DIN 28131 and ensure continuous particle suspension and consistent abrasive interaction with the propeller surface [11], [12], [15]. The container was mounted on a metal frame for structural support during operation.

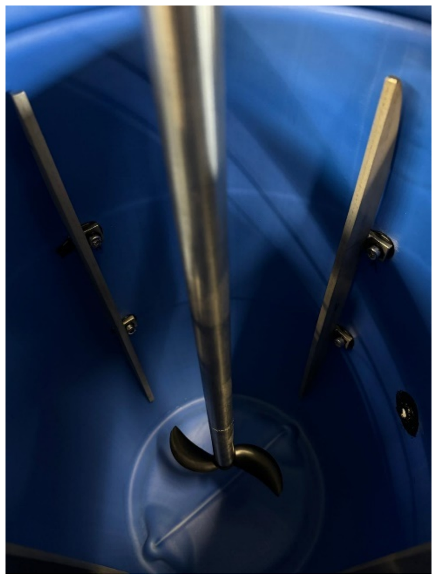

Fig. 1 The empty open head plastic drum equipped with vertical baffles, which was used for the wear tests. A Phantom propeller made of Physinit is visible in the middle and fixed at the end of the shaft.

The mixing system was driven by an SRTO-75-1500 electric motor operating at a fixed rotational speed of 1493 revolutions per minute (rpm). Propeller rotation was transmitted through a central shaft. The control of the rotational speed during operation was achieved by utilizing "AmaControl3" and "INT69 PYF Diagnostik" diagnostic units. The test medium consisted of water mixed with silicon carbide abrasive particles (grade F070, 180–250 µm), manually introduced into the tank in defined quantities to reach the desired particle concentrations for each trial. Silicon carbide as an abrasive material was chosen for its hardness and angular shape [8], [9]. A particle concentration of 80 g/l was used for three trials. The fourth trial used a higher concentration of 200 g/l.

Four different propellers with a uniform diameter of 150 mm were evaluated. Three of them featured a two-blade "Phantom" geometry, of which two were made of the modified polyamide composite Physinit and one made of conventional austenitic stainless steel (DIN EN 1.4301). A fourth propeller, made of stainless steel, followed a generic three-blade axial-flow design. No additional surface treatments were applied to the propellers prior to testing.

Each propeller was mounted individually and operated within the abrasive slurry at a constant rotational speed. The test vessel was sealed at the top with a lid to minimize splash.

Table 1 Half factorial design of experiments for the series of wear tests

Trial	Geometry	Material	Particle concentration
1	Phantom	Physinit	80 g/l
2	Phantom	Physinit	200 g/l
3	Phantom	Stainless steel	80 g/l
4	Three bladed	Stainless steel	80 g/l

A half factorial experimental design of experiments was applied, with three primary variables varied across test conditions: propeller material, propeller geometry, and abrasive particle concentration (Table 1). The rotational speed remained constant to ensure a consistent circumferential velocity of approximately 11.7 m/s across all trials. This circumferential velocity was chosen so that the model propeller has a similar blade tip speed as the original Phantom propeller at 9.6 m/s, since the impact velocity of particles is a major factor regarding erosive wear [9], [16]. One test was performed for each combination of parameters, resulting in four individual test runs. All the tests were conducted over a period of approximately seven days. Trial 1 was extended by another seven days after all trials were completed to see if the wear behaviour would change significantly.

The trials were regularly interrupted for the measurement of the propellers to document the continuous wear. Mass loss of the propellers was determined by weighing the specimens before, during and after the test using a precision scale "Brifit KA26" with a precision of 0.01 g. To account for the different densities of the materials only the relative mass loss was evaluated. To prevent measurement inaccuracies due to fluid residue, all propellers were thoroughly cleaned and dried prior to weighing. Diameter changes were recorded using a digital calliper with a precision of 0.01 mm, measuring from the centre of the propeller hub to the outer edge of the blade tips.

The wear behaviour was quantified based on relative mass loss and wear rate over time, as well as blade diameter reduction. To enable a direct comparison between the three-blade and Phantom propeller geometries, the mass loss values of the three-blade stainless steel propeller were normalized based on its surface area. The surface area of each propeller was determined using CAD data. A correction factor of 0.6378 was applied to adjust the wear measurements of the three-blade design to the smaller reference area of the Phantom geometry. This normalization ensured that differences in mass loss and wear rate could be interpreted independently of the propeller surface area. No additional surface roughness, hardness, or mechanical property data were included in the analysis.

3. Results

The following section presents the results of four tribological wear tests carried out on model propellers. The experiments were designed using a half factorial setup with four individual test runs, each representing a unique combination of geometry, material, and particle concentration. The outcomes are structured by the measured parameters: relative mass loss, change in diameter and the wear rate.

3.1. Relative mass loss

Among the four tested configurations, the highest mass loss was observed in the three-blade stainless steel propeller. This propeller experienced a mass reduction of 21.3 %. After applying the correction factor, this would compare to a 13.6 % reduction of mass, if the two geometries had the same surface area. The Phantom-type stainless steel propeller tested under the same concentration exhibited a relative mass loss of 13.3 %.

In comparison, the Phantom-type propeller made of the modified polyamide (Physinit) showed lower relative mass losses. At a slurry concentration of 200 g/l, the propeller lost 1.6% of its initial mass over the test duration. The same propeller type tested at 80 g/l showed a total relative mass loss of 1.4% after the initial trial and 2.8% over the extended runtime of fourteen days. The relative mass loss of the propellers is illustrated in Fig. 2.

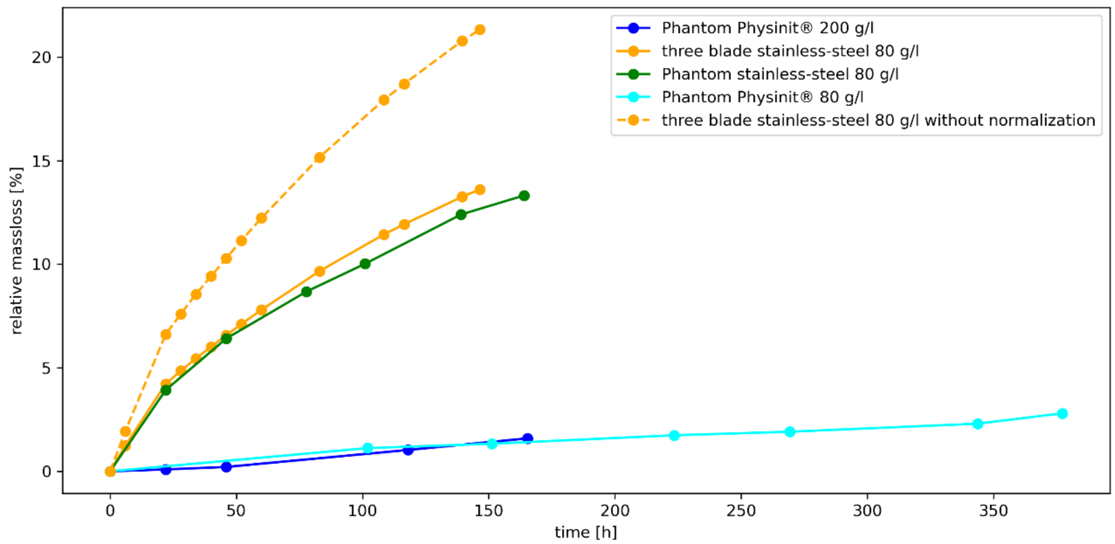

Fig. 2 Comparison of the relative mass loss of the four propellers during the trials. The correction factor of 0.6378 accounting for the surface area differences between the three-blade and the Phantom® propeller was applied to the values of the three-blade propeller.

3.2. Change in diameter

The stainless-steel Phantom propeller showed a continuous reduction in blade diameter across the test duration. With a final diameter of 121.85 mm, it experienced the largest diameter decrease. The three-blade stainless steel propeller also showed a decreasing trend in diameter, with a more pronounced change after approximately 50 hours of operation, finishing with a diameter of 135.20 mm.

The Physinit-based propellers showed delayed and less pronounced diameter changes. In the configuration with 200 g/l particle concentration, measurable diameter reduction occurred only after the second day of operation. By the end of the test period, the total diameter loss remained under 2 mm with a final diameter of 148.40 mm. At a particle concentration of 80 g/l the first measurable reduction in diameter occurred after six days. The final diameter of this propeller was 184.60 mm. There is no trend apparent that could be applied to all four curves in Fig. 3.

3.3. Wear rate

The wear rate was calculated based on the ratio of relative mass loss to test duration, expressed in percent per hour. The progression of wear rate over time for all four test configurations is illustrated in Fig. 4. The three-blade stainless steel propeller operated at a particle concentration of 80 g/l exhibited the highest initial wear rate, peaking at approximately 0.32 %/h before gradually declining over the course of the test. A similar decreasing trend was observed for the Phantom-type stainless steel propeller, although with a lower initial peak around 0.18 %/h and a more rapid stabilization.

Both Physinit-based propellers, tested at 80 g/l and 200 g/l respectively, showed significantly lower and more stable wear rates throughout the test duration. Their curves remained nearly flat, with rates remaining consistently below 0.01 %/h, except the Phantom Physinit propeller at 80 g/l whose wear rate peaked at 0.011 %/h before decreasing like the stainless-steel propellers.

All configurations demonstrated a declining wear rate over time, with the most pronounced drop observed in the metallic specimens. The wear behavior of the Physinit propellers remained consistent and showed no marked fluctuations during prolonged operation.

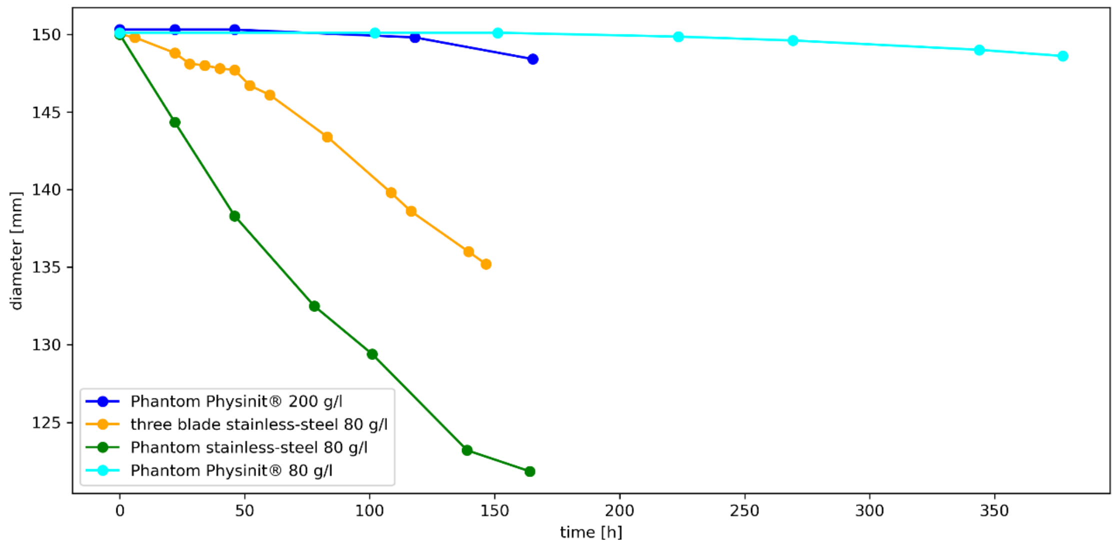

Fig. 3 Comparison of the development of the diameter of the four model propellers during the trials.

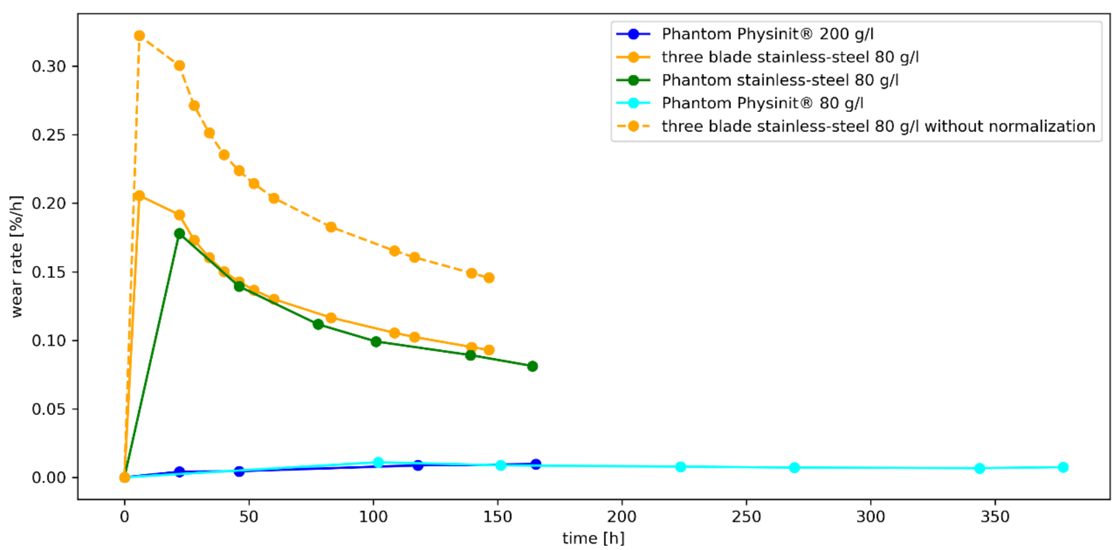

Fig. 4 Comparison of the wear rates of the four different model propellers during the trials.

4. Discussion

The results of the wear tests provide several indications regarding the influence of material, geometry, and operating conditions on the durability of submersible mixer propellers in abrasive environments. While the study was not intended to model a specific real-world application, the observed trends offer relevant insights into wear mechanisms and their potential consequences.

A comparison of the tested propeller materials revealed clear differences in wear behaviour under abrasive conditions. The stainless-steel specimens exhibited higher relative mass loss, more pronounced diameter reduction, and elevated wear rates across all configurations. In contrast, Physinit showed a slower and more uniform wear progression, with lower cumulative material loss over comparable or longer test durations. These differences may be attributed to the intrinsic material properties, such as surface hardness, elasticity, and resistance to microcracking. Furthermore, the wear on stainless steel surfaces tended to occur more rapidly in the early stages of the test, whereas the polyamide material exhibited delayed onset of measurable degradation. These findings suggest that the tested materials respond differently to the mechanical interaction with abrasive particles, particularly in regions with high impact velocity, such as the blade tips.

One key observation is the varying wear performance between the two propeller geometries tested. The Phantom geometry demonstrated a more uniform wear pattern (Fig. 5), which appears to be advantageous for maintaining safe and stable operation over time. In contrast, the three-blade stainless steel propeller exhibited increasing radial deformation during the final phase of the test, eventually leading to failure of the motor bearing. This suggests that not only the material but also the shape of the propeller has a direct effect on operational safety and mechanical integrity.

From a mechanical design perspective, the Phantom-type two-blade propeller, if capable of delivering similar thrust and hydraulic efficiency as the three-blade configuration, presents a significant benefit in terms of wear behaviour. With fewer blades and a streamlined geometry, material exposure is reduced while the overall power input remains constant. This would directly lower the wear surface area and, consequently, the accumulated degradation.

Fig. 5 Pictures of propellers before (gray) and after wear tests. From left to right: Phantom Physinit® 80 g/l; Phantom Physinit 200 g/l; Phantom stainless-steel 80 g/l; three-blade stainless-steel 80 g/l

Higher wear levels were consistently observed near the blade tips across all test configurations. This is likely due to increased local impact velocities at the outer diameter, as centrifugal force and peripheral speed are greatest in these regions. As propeller performance parameters such as thrust coefficient K_T and torque coefficient K_Q are strongly dependent on diameter - proportional to the fourth and fifth power, respectively [17] - even minor geometric degradation in this area can have a disproportionately large impact on hydraulic performance. A reduction in diameter due to wear therefore implies a significant loss in efficiency and delivered power.

The differences in abrasive particle concentration between the two test scenarios also influenced wear progression. The configuration with higher solid concentration showed increased mass loss and more rapid surface degradation. Although only one particle size distribution (F070 silicon carbide, 180–250 µm) was used, variations in local particle agglomeration, sedimentation, or suspension state during operation may have contributed to fluctuations in instantaneous wear rates. Additionally, the observed decline in wear rate over time, particularly in stainless steel specimens, may indicate a loss of abrasive effectiveness due to particle rounding [8] or settling, or the preferential removal of less resistant surface layers during early test stages.

While the observed trends are consistent within the scope of the experiments, direct extrapolation to real operating conditions must be approached with caution, since the wear is purposefully accelerated in laboratory test [9]. The test setup does not replicate the flow regime, chemical environment, or load profiles [9] of specific biogas, mining, or drilling applications. Therefore, the quantitative wear rates measured in this study are not intended to predict service life in practical installations but rather to serve as a comparative framework for evaluating relative material and design performance.

Finally, the correlation between mass loss and propeller performance degradation underscores the importance of considering wear in the design and material selection of mixing systems. Even moderate wear can result in measurable performance loss due to the nonlinear sensitivity of thrust and torque to geometric changes. This highlights the need for further investigation into the combined effects of mechanical loading, slurry rheology, and long-term surface erosion in complex real-world conditions.

5. Conclusion

This experimental study investigated the influence of propeller material, blade geometry, and particle concentration on the erosive wear behaviour of submersible mixer propellers under controlled slurry conditions. The results showed distinct differences in wear progression depending on the tested parameters.

The stainless-steel propellers exhibited higher relative mass loss, more significant diameter reduction, and greater wear rates compared to the modified polyamide (Physinit) propellers. In particular, the two-blade Phantom geometry made of Physinit demonstrated the most stable and uniform wear behaviour throughout the tests. Configurations with higher particle concentrations resulted in increased wear, and the blade tip regions were consistently identified as the most affected zones due to higher peripheral velocities.

The application of a half factorial design allowed for efficient identification of the main influences on wear behaviour, despite the limited number of test runs. While the specific conditions do not directly simulate real-world operational environments, the comparative results highlight the potential of certain material and geometry combinations to extend operational life and reduce performance degradation due to erosive wear.

Future work should focus on validating these findings under application-specific flow and loading conditions, incorporating fluid chemistry and real substrate interactions, as well as evaluating the long-term functional impact on thrust and mixing performance in biogas, mining applications or similar applications.

Declaration of competing interest

The authors declare a potential conflict of interest. Both the Phantom propeller geometry and the Physinit® material tested in this study are proprietary developments of PTM GmbH. The purpose of this research is, in part, to demonstrate the performance characteristics of these products under defined wear conditions. The findings are intended to support the technical evaluation and positioning of PTM’s own technologies.

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