

Analysis of 30° Paddle Blade Performance for Motor Power Reduction in a 10 kg Horizontal Dough Mixer

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Abstract

This study investigates the effect of paddle blade inclination on the performance of a 10 kg horizontal dough mixer used in small-scale bakery production. The existing mixer uses a 0° paddle blade and requires a high motor power of 4.85 kW, with a mixing time of approximately 60 minutes. Previous studies have shown that paddle geometry and inclination affect material movement, torque, and mixing performance; however, experimental studies on inclined paddle blades in small-capacity gasoline-engine-driven dough mixers remain limited. This study evaluates a 30° paddle-blade modification to reduce the motor power requirement and mixing time. Experiments were conducted at rotational speeds of 60, 70, and 80 rpm using a constant dough load of 10 kg. Motor power and mixing time were recorded for each operating condition. At 70 rpm, the original 0° blade was compared with the modified 30° blade under the same dough load and rotational speed. The results show that the 30° blade reduced motor power from 4.85 to 2.45 kW, corresponding to a 49.48% reduction, while mixing time decreased from 60 to 35 minutes. Based on the measured power and mixing duration, the estimated energy requirement decreased from 4.85 to 1.43 kWh, representing a 70.52% reduction. The inclined blade promotes combined radial-axial material movement, which can reduce localized dough accumulation and mechanical resistance. The results demonstrate that a 30° paddle blade is a practical modification for improving the tested mixer's performance.

Keywords: blade inclination; dough mixing; energy efficiency; horizontal mixer; motor power

Abstrak

Penelitian ini mengkaji pengaruh kemiringan paddle blade terhadap kinerja horizontal dough mixer berkapasitas 10 kg yang digunakan dalam produksi roti skala kecil. Mesin yang digunakan sebelumnya memiliki paddle blade dengan sudut 0° dan membutuhkan daya motor sebesar 4,85 kW dengan waktu pencampuran sekitar 60 menit. Penelitian terdahulu menunjukkan bahwa geometri dan sudut blade memengaruhi pergerakan material, torsi, dan kinerja pencampuran, tetapi penelitian eksperimental mengenai penggunaan paddle blade miring pada mixer adonan berkapasitas kecil dengan penggerak motor bensin masih terbatas. Penelitian ini mengevaluasi modifikasi paddle blade dengan sudut 30° untuk menurunkan kebutuhan daya motor dan waktu pencampuran. Pengujian dilakukan pada kecepatan 60, 70, dan 80 rpm dengan beban adonan tetap sebesar 10 kg. Parameter yang diamati adalah daya motor dan waktu pencampuran. Pada 70 rpm, paddle blade 0° dibandingkan dengan blade 30° pada beban dan kecepatan putar yang sama. Hasil menunjukkan bahwa blade 30° menurunkan daya motor dari 4,85 menjadi 2,45 kW atau sebesar 49,48%, sedangkan waktu pencampuran berkurang dari 60 menjadi 35 menit. Berdasarkan daya terukur dan waktu pencampuran, estimasi kebutuhan energi menurun dari 4,85 menjadi 1,43 kWh atau sebesar 70,52%. Kemiringan blade menghasilkan kombinasi gerakan material radial-aksial yang dapat mengurangi akumulasi adonan serta resistansi mekanis. Hasil penelitian menunjukkan bahwa paddle blade 30° merupakan modifikasi praktis untuk meningkatkan kinerja mesin mixer yang diuji.

Kata kunci: daya motor; dough mixing; efisiensi energi; horizontal mixer; kemiringan blade

1. Introduction

The bakery industry continues to grow, driven by increasing demand for processed food products, encouraging small- and medium-scale bakeries to improve production capacity and operational efficiency [1]. Dough mixing is an important stage because it affects gluten formation, water distribution, ingredient homogeneity, and final product quality [2]. Mechanical mixers are therefore widely used to obtain consistent mixing performance [3]. Horizontal mixers are particularly suitable for medium- and small-scale production because of their relatively simple construction and ability to

handle considerable dough loads [4]. Bread dough is a semi-solid material with high viscosity and elastic characteristics. These properties generate considerable resistance against mixing blades and consequently affect the required torque and motor power [5][6]. Inadequate blade geometry may increase mechanical resistance, energy consumption, component wear, and operational instability [7]. Field observations at Pabrik Roti Djawa showed that the existing 10-kg horizontal mixer uses a 0° paddle blade driven by a 6.5-HP gasoline engine through a 1:20 gearbox. The mixer requires approximately 60 minutes to obtain the required dough condition.

Previous studies have investigated the effects of rotational speed and mixer configuration on mixing performance [8-12]. Bao et al. reported that impeller configuration, blade inclination, blade number, rotational speed, and fill level influence material flow and torque in a cylindrical mixer [10]. Jadidi et al. also showed that paddle angle affects particle forces, mixing behavior, and mixer power consumption [5]. Wang et al. reported favorable mixing behavior at paddle angles of 30° and 45°, indicating that blade inclination affects the balance between circumferential and axial material movement [11]. Similar findings have been reported for inclined mixing blades, although the optimum configuration depends on mixer geometry, material properties, and operating conditions [12-15].

Most previous studies, however, focused on particulate materials, numerical simulations, or mixer configurations different from those used for bread dough. Therefore, their results cannot be directly transferred to a small-capacity dough mixer. Experimental evaluation of an inclined paddle blade as a practical modification for reducing motor power in a gasoline-engine-driven horizontal dough mixer remains limited.

In this study, a 30° paddle blade was selected to introduce an axial component of dough movement while maintaining radial mixing. The rotational speeds of 60, 70, and 80 rpm were selected based on the practical operating range of the investigated mixer. The 70 rpm condition was subsequently used to compare the original 0° blade and modified 30° blade under identical dough load and rotational speed. The objective was to evaluate the effect of the 30° blade on motor power, mixing time, estimated torque, and energy requirement in a 10 kg horizontal dough mixer.

2. Materials and Methods

2.1. Horizontal mixer specifications

The experiment was conducted using a horizontal mixer with a 10 kg capacity, designed for mixing bread dough in small-scale bakery production. The system is driven by a 6.5 HP gasoline engine connected to a gearbox with a 1:20 reduction ratio. Power is transmitted from the engine to the mixing shaft via a belt-and-pulley mechanism. The detailed specifications of the mixer are presented in Table 1.

Table 1. Specifications of the horizontal mixer

No	Component	Specification
1	Capacity	10 kg
2	Drive Motor	6.5 HP gasoline engine
3	Gearbox	WPA 60, ratio 1:20
4	Transmission System	Belt and pulley
5	Operating Speed	60–80 rpm
6	Hopper Material	Stainless Steel SUS 304
7	Blade Material	Stainless Steel SUS 304
8	Blade Type	Paddle blade, 30° inclination

The horizontal cylindrical hopper provides the mixing chamber, while the central shaft transmits rotational motion to the paddle blades. The modified blade generates a combination of radial and axial material movement during rotation.

2.2. Experimental variables

The experimental variables used in this study include independent variables, dependent variables, and controlled parameters. These variables are summarized in Table 2. The experiments were conducted with a constant dough load while varying the mixing shaft's rotational speed.

Table 2. Experimental variables and parameters

No	Variable Type	Description
1	Independent variable	Rotational speed (60 rpm, 70 rpm, 80 rpm)
2	Dependent variable	Motor power (kW)
3	Dependent variable	Mixing time (minutes)
4	Constant load	Bread dough 10 kg
5	Reference condition	Paddle blade with 0° inclination

2.3. Performance evaluation and energy calculation

Mixer performance was evaluated based on motor power consumption and mixing time. Motor power consumption was recorded during steady mixer operation at each specified rotational speed, and mixing time was recorded from the start of mixing until the predetermined operational criterion for a sufficiently homogeneous dough was met. The mechanical relationship between power, torque, and angular velocity is expressed as:

$$P = T \times \omega \quad (1)$$

where P = power (W), T = torque (N.m), and ω = angular velocity (rad/s)

The total energy consumption during the mixing process is calculated using:

$$E = P \times t \quad (2)$$

where E = energy consumption (kWh), P = motor power (kW), and t = mixing time (hour)

These equations are used to evaluate the effect of paddle blade geometry on motor power requirement and energy efficiency during the mixing process.

2.4. Experimental procedure

Before each test, the mixer was inspected to ensure that the shaft, gearbox, belt-and-pulley system, bearings, and paddle blades were in proper operating condition. A constant dough mass of 10 kg was loaded into the hopper. The mixer was operated at 60, 70, and 80 rpm using the 30° paddle blade. Motor power consumption and mixing time were recorded for each operating condition. The 70 rpm condition was subsequently used to compare the original 0° blade and modified 30° blade under the same dough load and rotational speed. The experimental sequence is shown in Figure 1.

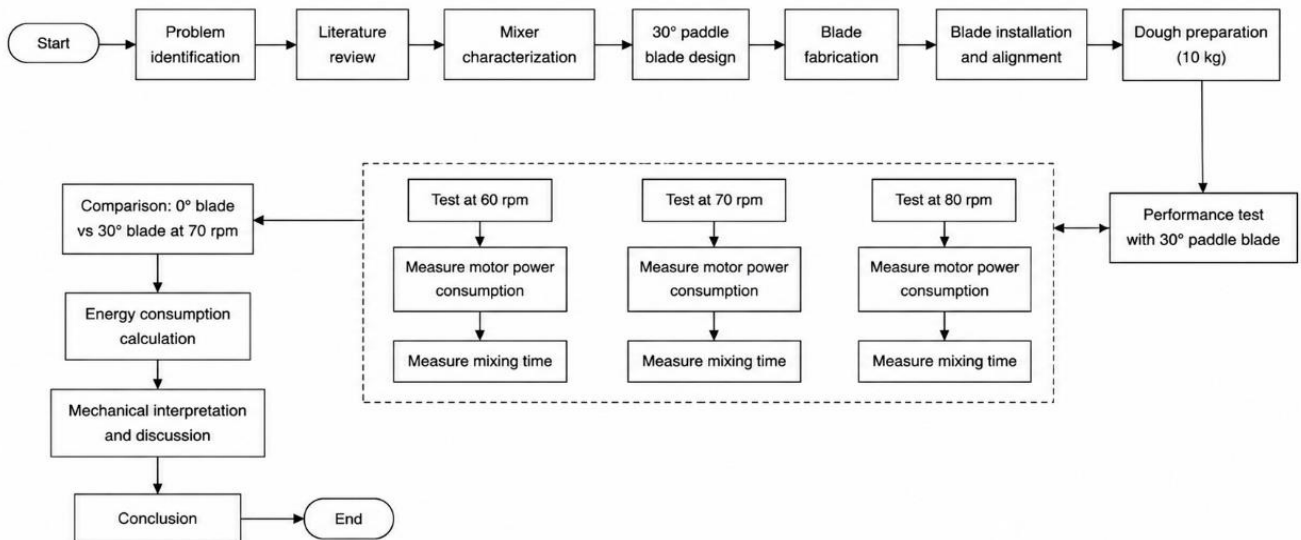


Figure 1. Experimental procedure

3. Results and Discussion

3.1. Design of the horizontal mixer

Figure 2 presents the overall 3D configuration of the horizontal dough mixer. The main components consist of the hopper, gasoline engine, belt-and-pulley transmission, gearbox reducer, mixing shaft, paddle blades, bearing supports, and structural frame. The gasoline engine supplies the rotational power, which is transmitted through the belt-and-pulley mechanism and reduced by the gearbox before being delivered to the mixing shaft.

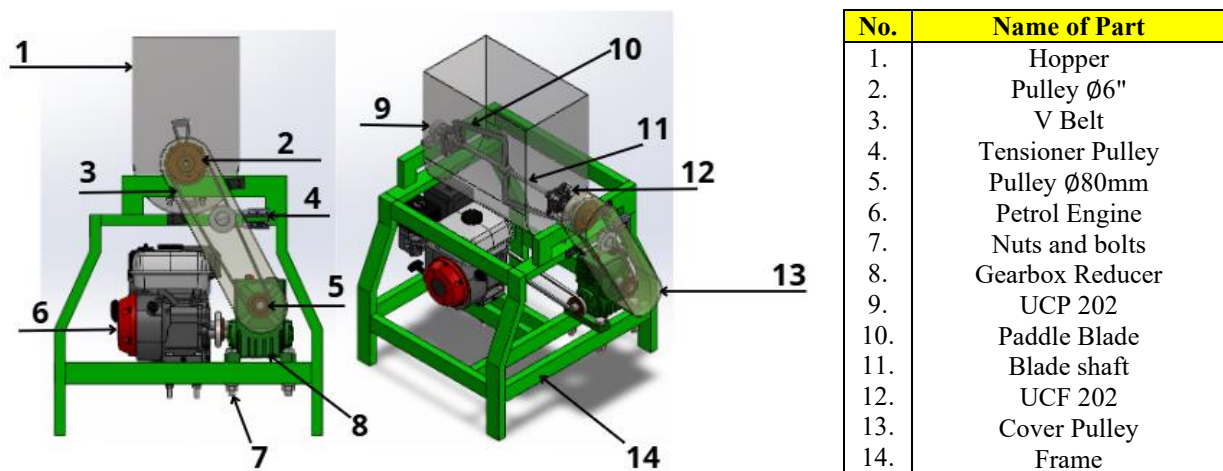


Figure 2. 3D isometric design of the horizontal mixer

The hopper provides the working volume for the 10 kg dough load, while the mixing shaft supports the paddle blades. The blades are arranged symmetrically along the shaft to maintain rotational balance and reduce mechanical imbalance during operation. Figure 3 shows the geometry of the modified paddle blade. The blade is inclined at 30° relative to the reference plane used for the blade geometry. The inclination introduces an axial component of dough movement in addition to the circumferential or radial component generated by blade rotation.

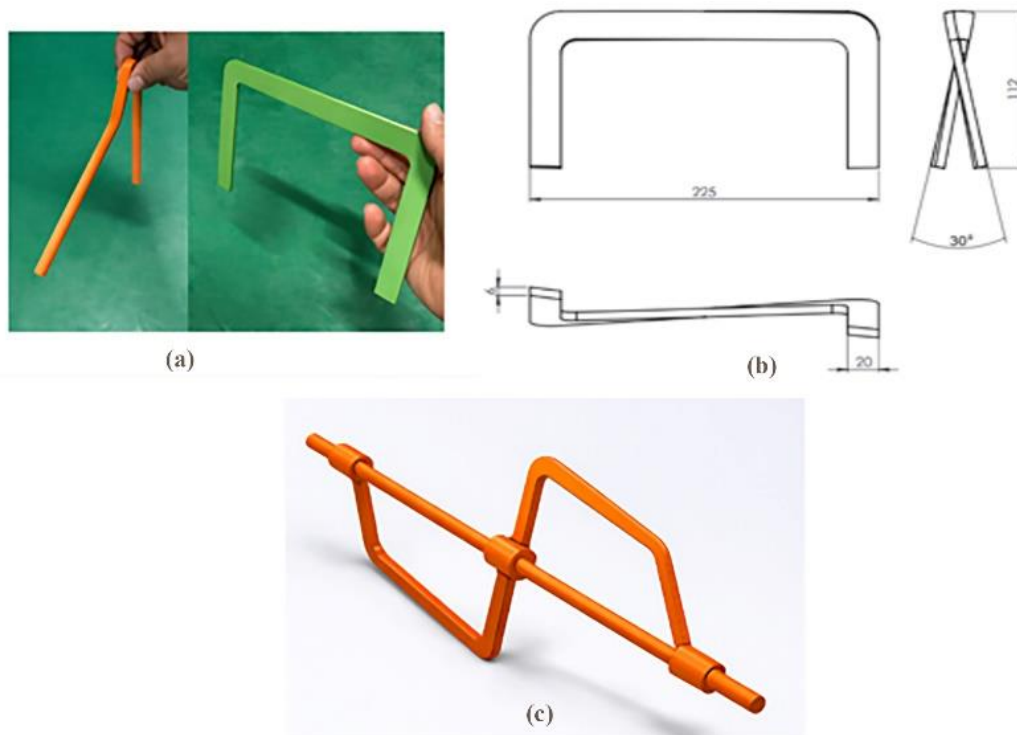


Figure 3. Geometry of the 30° paddle blade, (a) blade profile, (b) blade dimensions, and (c) assembled blade

The 30° inclination was selected to produce a combination of radial and axial material flow during mixing. This configuration allows the dough to circulate along the mixing shaft while simultaneously moving toward the hopper wall, thereby improving mixing distribution and reducing dead zones.

The fabricated machine and the installation of the 30° paddle blade inside the hopper are shown in Figure 4. The blades are made of SUS 304 stainless steel to ensure corrosion resistance and compliance with food-processing hygiene standards. Figure 4 shows that proper shaft alignment was applied during installation to maintain stable rotation and minimize mechanical imbalance during operation.

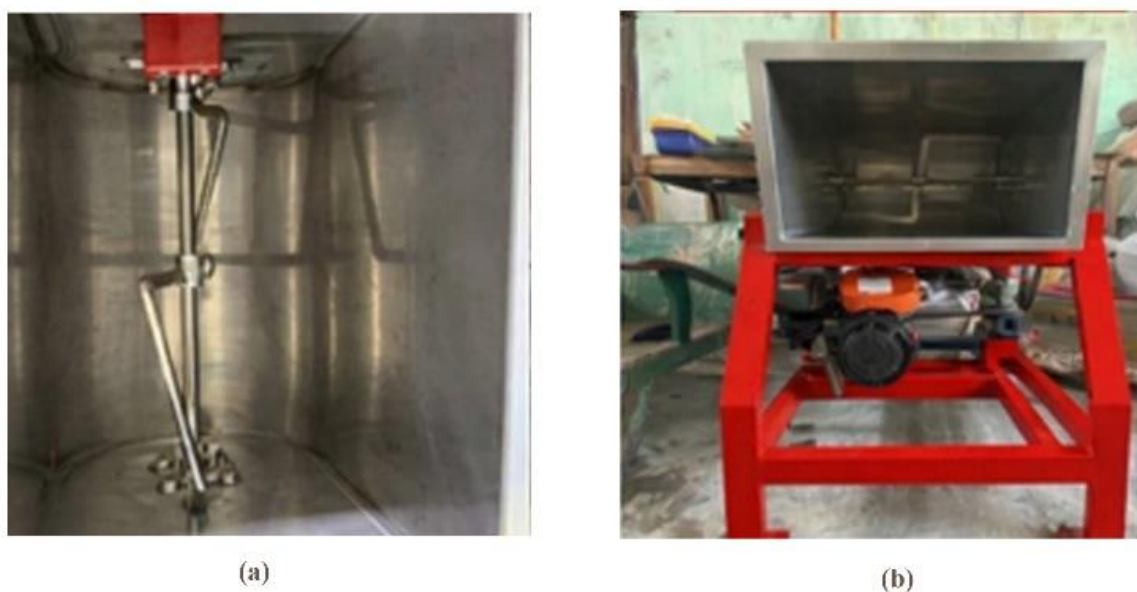


Figure 4. Fabrication and installation of the horizontal dough mixer (a) 30° paddle blade, (b) mixer assembly

3.2. Performance test results

Performance tests were conducted to evaluate the effect of the 30° paddle blade on motor power consumption and mixing time. The experimental results are summarized in Table 3.

Table 3. Performance test results at different rotational speeds

Rotational Speed (rpm)	Motor Power (kW)	Mixing Time (minutes)	Operating Condition
60	2.3	40	Stable
70	2.45	35	Stable
80	2.65	32	Stable (slight vibration)

The results show that increasing rotational speed from 60 to 80 rpm increased motor power consumption from 2.30 to 2.65 kW. At the same time, mixing time decreased from 40 to 32 minutes. The increase in power requirement is consistent with the higher mechanical demand associated with increased shaft speed, while the reduction in mixing time indicates faster material circulation inside the hopper.

Although increasing speed increased motor power, it also reduced mixing time, with the largest practical improvement observed between 60 and 70 rpm. However, the 80 rpm condition produced slight vibration. This observation indicates that increasing rotational speed should not be considered in isolation from mechanical stability. The appropriate operating condition should consider both mixing performance and mechanical behavior.

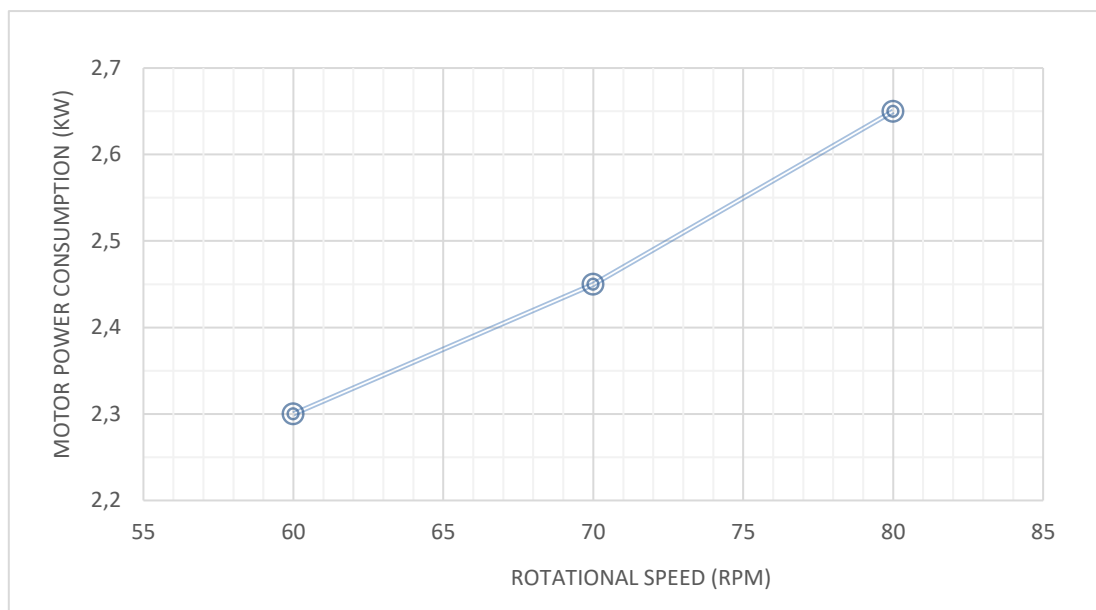


Figure 5. Relationship between rotational speed and motor power

Figure 5 shows an increasing trend of motor power consumption with rotational speed. This trend is mechanically reasonable because shaft power is related to torque and angular velocity through Equation (1). Nevertheless, the relationship should not be interpreted as strictly linear, as torque can also vary with material flow and dough resistance.

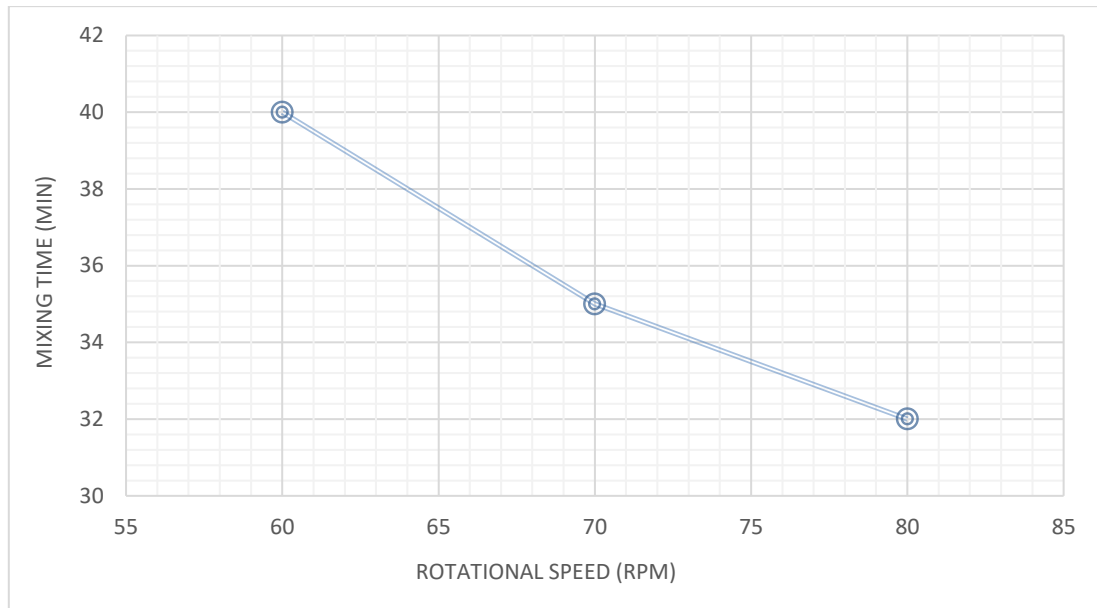


Figure 6. Relationship between rotational speed and mixing time

The mixing time decreased from 40 minutes at 60 rpm to 35 minutes at 70 rpm and 32 minutes at 80 rpm (Figure 6). Higher rotational speed increases the frequency of blade–dough interaction and promotes faster circulation within the hopper. However, the reduction in mixing time becomes smaller from 70 to 80 rpm, while slight vibration was observed at 80 rpm. This suggests that further increases in rotational speed may yield diminishing returns and increase mechanical instability.

3.3. Motor power reduction and mechanical interpretation

The effect of paddle geometry was evaluated by comparing the original 0° blade with the modified 30° blade at 70 rpm. The same rotational speed and dough load were used to ensure that the comparison focused on blade geometry, as shown in Table 4.

Table 4. Comparison of motor power at 70 rpm

Parameter	Blade 0°	Blade 30°	Difference	Reduction (%)
Motor Power (kW)	4.85	2.45	2.4	49.48%

The 30° blade reduced motor power from 4.85 to 2.45 kW, corresponding to a 49.48% reduction. Because both configurations were tested at the same rotational speed, the angular velocity was constant. According to Equation (1), a reduction in power indicates a corresponding reduction in the estimated torque, provided that the measured power represents the same quantity for both configurations.

At 70 rpm, the angular velocity is approximately 7.33 rad/s. The estimated torque was approximately 662 N·m for the 0° blade and 334 N·m for the 30° blade. These values are calculated from power and rotational speed and should therefore be interpreted as estimated rather than directly measured torque.

The observed power reduction may be associated with changes in dough movement. The original 0° blade primarily promotes circumferential or radial movement. For viscous dough, this movement may result in localized accumulation

and increased blade resistance. In contrast, the 30° blade introduces an axial component, allowing dough to move along the shaft while maintaining radial circulation. This combined movement can distribute the dough more effectively and reduce localized mechanical resistance.

The result is consistent with previous studies showing that blade inclination affects material movement, force, torque, and mixer power [5], [10], [11], [15]. However, the present result should not be interpreted as establishing 30° as a universal optimum because the appropriate blade angle depends on mixer geometry, material properties, fill level, and rotational speed. Previous studies have demonstrated that paddle inclination influences material flow, mixing force, torque, and power demand. Jadidi et al. [5] reported that mixer design parameters affect the mechanical behavior and performance of twin-paddle mixing. Bao et al. [10] showed that impeller configuration and operating conditions influence particle flow and torque, while Wang et al. [11] found that paddle angle affects mixing behavior. These findings support the present observation that blade inclination can alter the mechanical resistance experienced by the mixing system. However, unlike previous studies, the present work experimentally evaluates an inclined paddle blade in a small-capacity horizontal dough mixer driven by a gasoline engine.

3.4. Estimated energy requirement

Table 5 describes the energy requirement at 70 rpm, calculated from motor power and mixing time using Equation (2).

Table 5. Estimated energy requirement at 70 rpm

Parameter	Blade 0°	Blade 30°	Difference	Energy Saving (%)
Power (kW)	4.85	2.45	2.40	49.48
Mixing time (minutes)	60	35	25	41.67
Energy (kWh)	4.85	1.43	3.42	70.52

The estimated energy requirement decreased from 4.85 to 1.43 kWh, corresponding to a 70.52% reduction. The reduction exceeds that in instantaneous motor power because the 30° blade simultaneously reduced both the power requirement and the mixing duration.

Therefore, the energy benefit results from two effects: lower mechanical power demand and shorter processing time. However, because a gasoline engine drives the mixer, these values represent an estimated energy requirement based on measured power and mixing duration, rather than direct fuel-energy consumption. Direct fuel consumption measurements are required to quantify the actual energy and economic benefits.

4. Conclusion

The 30° paddle blade improved the performance of the investigated 10 kg horizontal dough mixer. At 70 rpm and a constant 10 kg dough load, motor power decreased from 4.85 to 2.45 kW, corresponding to a 49.48% reduction. Mixing time also decreased from 60 to 35 minutes.

Based on the measured motor power and mixing duration, the estimated energy requirement decreased from 4.85 to 1.43 kWh, representing a 70.52% reduction. The improvement is attributed to the combined radial-axial dough movement generated by the inclined blade, which enhances material circulation and reduces localized mechanical resistance.

The results are specific to the investigated mixer, 10 kg dough load, and 30° blade configuration. Further research should evaluate other blade angles, dough loads, and rotational speeds, along with direct measurements of torque and fuel consumption, and a quantitative assessment of dough homogeneity.

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