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Prototype of Laboratory Scale Centrifuge for Gum Crude Palm Oil (CPO) Separate

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Abstract This study concentrates on the design and construction of a laboratory-scale centrifuge for the separation of gum from crude palm oil (CPO). The extraction of gum from CPO is essential in the palm oil sector to guarantee that the finished product adheres to quality standards and is safe for consumption. We engineered the prototype centrifuge to accommodate six 600-mL bottles and achieve a maximum rotational speed of 1400 rpm. The design procedure utilised Autodesk Inventor software for CAD modelling and computations to ascertain the centrifugal force, power capacity, and shaft diameter. The process of manufacturing entailed cutting and shaping stainless steel into the necessary components, subsequently followed by drilling and milling operations for mounting points and interfaces. We implemented surface treatment to augment corrosion resistance and elevate visual appeal. The assembling procedure encompassed component integration, motor incorporation, and control system configuration. The experimental configuration involved centrifugal testing utilising 600-mL glass bottles with time intervals of 10, 20, 30, and 40 minutes at an average rotational speed of 924 rpm. The experiment showed that the centrifuge worked well to separate the gum and other contaminants from the CPO. The best separation happened after 40 minutes of centrifugation.

Keywords: Prototype, CPO, centrifuge, gum, purification

1. INTRODUCTION

The crude palm oil (CPO) industry is an integral part of the edible oil market. However, the purification process is often hampered by impurities such as gums consisting of phospholipids and hydrophilic molecules. The removal of such polar impurities is the key to enhancing the quality and stability of the final product as well as improving the overall refining process. To date, the standard approach to gum separation involves chemical methods and high-capacity machinery that are expensive and resource-intensive, hence difficult to apply in small or laboratory settings. In this regard, the creation of a prototype laboratory-type centrifuge is advantageous for efficient and accurate gum separation from CPO.

A scalable and compact centrifuge would allow researchers and small scale producers to test and refine the separation before moving on to larger industrial applications. Such a prototype serves not only for an enhancement of refining technologies but is also economically viable as it reduces the volume of chemicals and wastes generated. In this article, we describe the design, development and testing of a low cost laboratory centrifuge prototype intended for the separation of gum from crude palm oil. The study aims at improving the centrifugal force

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and the separation efficiency in palm oil refining, showing the application of centrifugal separation and its factors in process of palm oil refining. The prototype is cheap and eco-friendly and therefore presents a better option for palm oil industry in enhancing gum removal from CPO. Achieving widespread implementation of this technology advances the dual objectives of increasing the sustainability and profitability of palm oil processing. This initiative is especially important in the context of the growing international demand for high quality palm oil and the ability of the refining processes to reduce their ecological footprint. The findings of this research have the potential to bridge the gap between laboratory-scale testing and industrial applications, offering valuable implications for both academic research and the palm oil industry.

2. LITERATURE REVIEW

Refining and production of crude palm oil (CPO) proves to be vital in the market of oils and fats, however some impurities are still troubling the oil refining process, especially gums containing phospholipids. Thus, it is crucial to remove the gums in order to improve the quality of palm oil as well as to minimize the cost of refining. Gums are usually removed by chemical or mechanical means. These, however, are costly and do not contribute positively to the environment. Newer methods of centrifugal separation have been reported recently as a more forward-looking and effective option. The present review attempts to examine how centrifugal separation processes for the removal of gum from CPO have evolved over the years covering the basic principles, application and recent trends of the laboratory scale separation processes.

Centrifugal Separation in Oil Refining

Centrifugal separation leverages differences in density between impurities and oil to achieve separation. This principle has been widely applied in the edible oil industry for tasks such as sludge removal and clarification (Mehta & Patel, 2015). In CPO refining, gums are denser than oil, making them ideal candidates for centrifugal separation. Suhendra and Zulkifli (2012) highlighted the benefits of laboratory-scale centrifuges in understanding the dynamics of separation processes. Their study demonstrated that small-scale centrifuge systems provide valuable insights into operational parameters, including centrifugal force, rotational speed, and residence time. These findings underscore the potential of laboratory-scale prototypes for optimizing gum removal processes before scaling up to industrial applications.

Challenges and Innovations in Centrifuge Design

Although centrifugal separation procedure offers several advantages, it possesses some challenges too. To begin with, it still needs accurate adjusting to cope with different classes of CPO impurities and operates at a very high energy requirement. Recent works have aimed at overcoming these problems by coming up with new materials and improved designs. Kumar and Sreenivasan (2021) studied the influence of rotor geometric and material parameters on the efficiency of the separation. The results of the study show quite clearly that optimized designs can positively affect the energy consumed on the process and enhance the separation. In the same context, Chong and Ng (2018) reported the incorporation of advanced sensors and automation into centrifuge prototypes to allow for automatic monitoring and adjustment of operational parameters. Such innovations are very important in improving the centrifugal separation processes to low-scale manufacturers and researchers.

Sustainability and Environmental Impact

Concerns over environmental aspects set a priority for sustainable practices in palm oil production and refining. According to Tan and Lau (2019), sustainable practices in refining palm oil, including the centrifugal separation process, can also help to reduce the consumption of water and chemicals. The authors noted that centrifugal systems utilize less water as slurry, generating lesser wastewater compared to the conventional systems. Yusoff and Hansen (2010) examined the potential for emission reduction of greenhouse gases in the production of palm oil and considered centrifugal devices as one of the possible directions. Further application of renewable energy sources for the driving forces in operation of laboratory centrifuge prototypes intensifies their sustainability. Laboratory Centrifuge prototypes also has potential for the development of a laboratory model that would help in understanding how the central concepts of the centrifuge operate in a real world setting. Both Suhendra and Zulkifli (2012) and Kumar and Sreenivasan (2021) stresses the role of such systems towards addressing separation of multiple factors responsible for its efficiency. Further research should be directed towards more intricate materials and IOT based centrifugal systems to enable detail separation with consistent scalability. Besides, joint efforts of university and company researchers may facilitate the use of these prototypes for commercialization in the refining processes. The centrifugal prototypes for the separation of gum during CPO refining would revolutionize the industry through implementing new protocols and processes for sustainability in the refining CPOs.

3. METHODS

Creating a laboratory-scale centrifuge for the separation of gum from crude palm oil (CPO) involves several steps, from the design and fabrication of the centrifuge to testing its efficacy. The methods section for a project report or research paper detailing the development of such a prototype would typically include the following components:

Design Specifications

- Capacity: The capacity of the centrifuge is six bottles, each bottle 600 mL. The total volume is 3600 mL or 3.6 litres.
- Speed: The maximum rotation speed of the centrifuge is 1400 rpm, using a 1/4 HP electric machine. This tool has a speed of 924 rpm.
- Material: The material used for the frame is UNP carbon steel with a width of 50 mm, a height of 30 mm, and a thickness of 2 mm. The rotor material is carbon steel using a strip steel plate with a width of 19 mm and a thickness of 2 mm. For the rotor shaft, ST 41 iron material is used; the size is 25.4 mm in diameter and 700 mm in length

***Figure 1**. Rotor and sample CPO*

CAD Modeling

Design specifications, the software used in the tool design process is Autodesk Inventor.

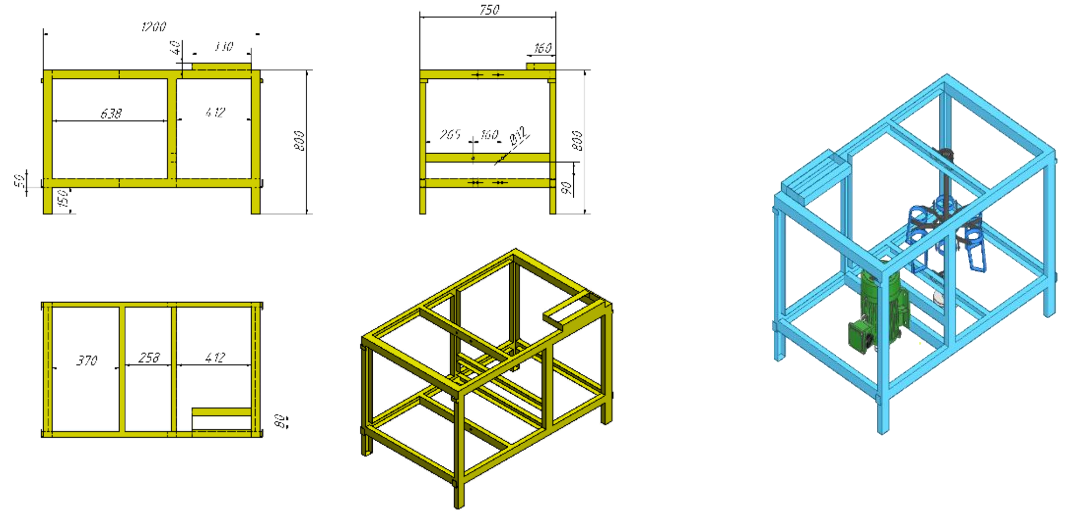

Figure 2. *Design of Centrifuge Equipment*

Operating the stress analysis level in the rotor on a tool with a mass of 0.472 kg is extremely safe. Using a bottle weight of 160 gram, we can calculate the test mass as 472 gram, or 0.472 kg, which includes the bottle's contents. To find out the safety factor, namely SF 2.18 Mn

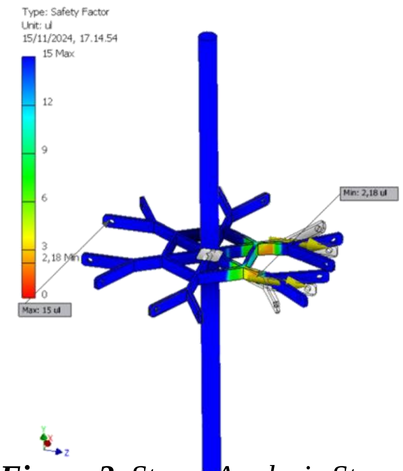

Figure 3. *Stress Analysis Stress Safety Factor*

Design Calculation

In the process of designing a centrifuge, there are several main components that are designed and analyzed, namely the centrifuge rotor, belt and pulley transmission, and the determination of the electric motor power used.

The following equation calculates the magnitude of the centrifugal force, which is necessary to design a centrifuge rotor:

$$F_s = m.\omega^2.r \quad (1)$$

Where Fs is centrifugal forces, m is mass, ω is angular velocity, and r is radius.

To find the angular velocity, we will use the following equation:

$$\omega = \frac{N_2.2\pi}{60} \quad (2)$$

$$N_2 = \ rotation\ machine\ (rpm)$$

After determining the centrifugal force value, use the following equation to determine the centrifuge's power capacity value:

$$p = \ \omega.T \quad (3)$$

Where P is power, ω is angular velocity, and T is torsi
To find the torque, use the following equation:

$$T = F.r \quad (4)$$

Where T is torque, F is force, and r is radius,

$$F = m.a \quad (5)$$

Where F is Force, m is mass, and a is acceleration.
The calculation of engine rotation acceleration in a centrifuge machine depends on how long it takes the machine to transition from a stationary state to a rotating state and reach its maximum rotation speed. We calculate acceleration using the following equation:

$$a = \frac{\Delta v}{\Delta t} \quad (6)$$

Where a is acceleration, Δv is speed difference, and Δt is time difference
To find out the linear velocity, use the following equation

$$v = r.\omega \quad (7)$$

Where v is velocity linier, r is radius, and ω is angular velocity.
If the power required is known, then we will determine the shaft diameter. We use the following equation.

$$d = \sqrt[3]{\frac{16.T}{\pi.\tau}} \quad (8)$$

Where d is diameter shaft, T is torsi, and τ is torsional allowable shear stress

Manufacturing Process

Component manufacture

- Cutting and Shaping: Use techniques like laser cutting, CNC machining, and water jet cutting to shape the stainless steel into the required components (rotor, housing, etc.).
- Drilling and Milling: Perform precision drilling and milling operations to create mounting points and interfaces for assembly.
- Surface Treatment: Apply finishes to improve corrosion resistance, reduce wear, and enhance aesthetic appearance. This might include polishing, anodizing, or coating processes

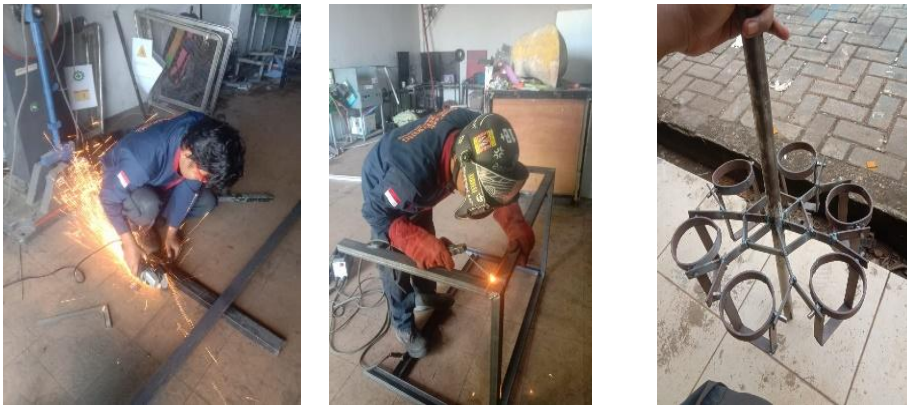

Figure 4. *Manufacturing Process*

Assembly

- Component Assembly: Assemble all mechanical components, including rotor installation, fitting of seals and bearings, and securing with fasteners.
- Motor Integration: Install the motor and ensure it is properly aligned with the rotor. Test the motor function to ensure operational stability.
- Control System Setup: Integrate electronic control systems that manage the operation of the centrifuge, such as speed control, temperature monitoring, and safety features

***Figure 5**. Assembly Product*

Experimental Set Up

Centrifugal testing requires crude palm oil (CPO) according to the capacity of the tool. The test was carried out using a 600-mL glass. The test time variations were 10 minutes, 20 minutes, 30 minutes, and 40 minutes with an average speed of 924 rpm. And the sediment will be observed for each specified time variation until the best separation between gum and CPO is seen.

4. RESULTS

After completing the centrifugation process for separating gums and impurities from crude palm oil (CPO), it is crucial to analyze the results and discuss the outcomes. Visual results of testing the CPO centrifuge with time variations of 10 minutes, 20 minutes, 30 minutes, and 40 minutes.

(a) 10 minutes

(b) 20 minutes.

(c) 30 minutes.

(d) 40 minutes

Figure 6

In the test results, namely:

a. CPO that was rotated for 10 minutes still looked cloudy even though the gum and dirt had been separated
b. CPO that was rotated for 20 minutes still looked cloudy but not as cloudy as CPO that was rotated for 10 minutes.
c. CPO that was rotated for 30 minutes looked clean even though there was still thin sediment still flying mixed with the oil.
d. CPO that was rotated for 40 minutes was clean and all the sediment was under the glass.

Efficiency in the CPO centrifugation process will be measured by weighing the CPO before being tested on the device, and after being tested, the weight of the clean oil and gum will be weighed.

(a) CPO is weighed before entering the centrifuge; the initial weight of CPO is 472 gram.

Figure 7

(b) CPO, after being tested in a centrifuge, it can be seen that the oil and gum have separated

Figure 8

(c) Clean CPO is weighed and weighs 399 gram

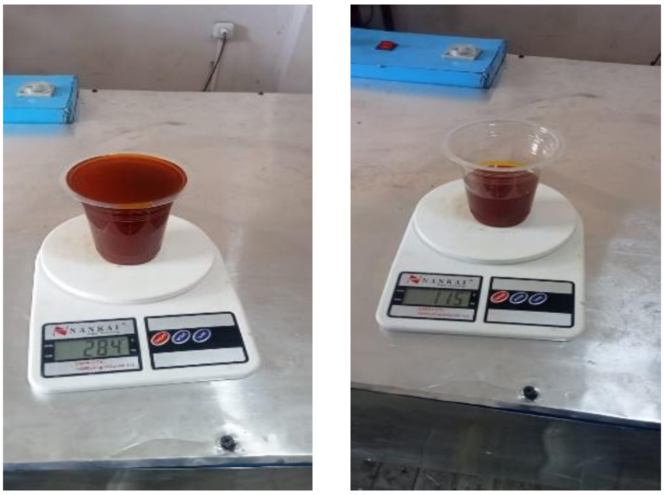

Figure 9

(d) Comparison of clean oil and gum

Figure 10

(e) Gum weight: 175 gram

Figure 11

CPO quality will be seen before and after testing

Figure 12

Operational Parameters

For motor power, it is 220 volts and 2.9 amperes. The noise of the centrifuge will be measured with the Sone Metre application, as for the highest noise value 95 decibels and the lowest 48 decibels.

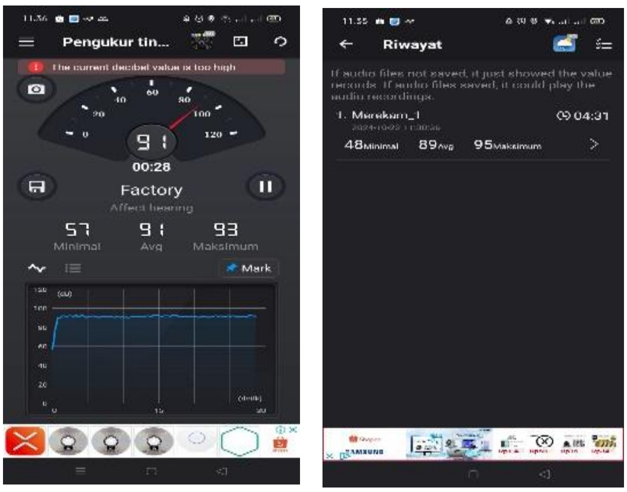

Figure 13

5. DISCUSSION

The laboratory-scale centrifuge prototype for gum separation in crude palm oil (CPO) achieved notable success in its operational design and performance testing. With a capacity to process up to 3.6 liters and an optimized rotational speed of 1400 rpm, the prototype demonstrated consistent and effective separation of gum from CPO under varying time intervals. The experimental results indicate that longer centrifugation durations improve the clarity of the oil and reduce sediment in the liquid phase. Specifically, a 40-minute centrifugation period resulted in the most effective gum removal, leaving a visually clear oil with sediment predominantly settled at the bottom of the container. This outcome aligns with theoretical predictions that centrifugal force enhances the separation of components with significant density differences, as gums are heavier than the oil matrix. The prototype’s performance suggests its capability as a practical tool for small-scale producers to refine CPO and improve product quality.

Moreover, the centrifuge's design considerations, including the use of durable materials such as stainless steel and precise CAD modeling, were instrumental in ensuring both functionality and safety. By accommodating multiple 600-mL bottles and maintaining an average speed of 924 rpm during testing, the device ensured uniformity in gum removal across all samples. Additionally, noise levels were monitored, revealing that the centrifuge operates within tolerable sound limits, enhancing its usability in laboratory or small-scale production environments. While the results underscore the device's effectiveness, the study also highlights areas for further improvement, such as reducing operational noise levels and optimizing energy consumption. Exploring alternative materials and incorporating IoT-enabled sensors for real-time monitoring could enhance the efficiency and scalability of the prototype, making it more appealing for broader industrial applications.

The implications of this study are significant for the palm oil industry, particularly for small-scale and decentralized production units. The centrifuge prototype provides a cost-effective and environmentally friendly alternative to conventional chemical degumming processes, reducing dependency on costly inputs and minimizing wastewater generation. Furthermore, this innovation supports local value addition, enabling small producers to process crude palm oil on-site rather than relying on centralized facilities. By improving the accessibility and affordability of advanced refining tools, this research contributes to more equitable and sustainable palm oil production systems. Future research should focus on refining the centrifuge’s automation capabilities and evaluating its performance with diverse CPO samples to establish broader applicability. This prototype serves as a foundation for advancing separation technologies, paving the way for improved refining practices in the edible oil sector.

6. CONCLUSION

The study effectively designed and evaluated a laboratory-scale centrifuge for the extraction of gums and contaminants from crude palm oil (CPO). The centrifuge features a 3.6-liter capacity and an optimised rotational speed of 1400 rpm, effectively eliminating contaminants and enhancing the quality of CPO. The prototype effectively addressed the particular requirements of small-scale farmers and producers, showcasing a feasible option for cost-effective and efficient on-site processing. The findings indicated that the oil's clarity improved with extended centrifugation durations, with optimal separation attained after 40 minutes. The oil quality was markedly improved, demonstrated by the decrease in contaminants and silt, underscoring the centrifuge's capability to provide high-value crude palm oil appropriate for many applications, including culinary uses, cosmetics, and biofuels.

This innovation offers a solution for small-scale producers to address prevalent constraints, such as elevated transportation expenses, restricted access to sophisticated equipment, and quality assurance difficulties. The advancement of the centrifuge enhances efficiency and enables companies to attain increased autonomy and sustainability in their operations. Moreover, by advocating for local processing, the centrifuge diminishes the environmental impact of palm oil production and conforms to global sustainability objectives. Future endeavours may concentrate on expanding the technique for wider use, incorporating sophisticated control systems for improved accuracy, and investigating alternate materials to further decrease expenses. This work establishes a robust foundation for enhancing small-scale CPO processing and promotes a more sustainable and inclusive palm oil sector.

LIMITATION

When making the tool, it is important to remember that when welding the rotor, because the rotor will receive centrifugal force that will rotate the glass with mass, if the welding does not meet the welding SOP, the glass support frame will be thrown, which is very dangerous because the machine rotation can throw the glass and frame, endangering the user of the tool, and always use K3 equipment when operating it.

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