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Design a Data Collection System for Palm Kernel Screw Press

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Abstract. The paper describes the various materials and methods used to create a functioning prototype of a mass flow rate data collection system which is applicable to the palm kernel screw press machine only. The system was then used to obtain crucial information through a series of tests which include the load cell calibration test which resulted in a maximum error of 5% deviation from the actual value of mass at higher loads. The Bluetooth Module and Arduino Uno communication test however, brought about great results as the prototype was found to function as intended and had a 100% success rate to perform optimally in a real-life situation. The mass flow rate data collection system will be able to notify the user when the screw press machine has reached a critical point for maintenance and also help in the troubleshooting process to locate the source of the decrease in performance of the screw press.

INTRODUCTION

The starting point of the oil palm plant being recognized as a plantation crop was in South East Asia. Following that recognition, the first oil palm plantation to be used for commercial purposes was set-up in Sumatra, Indonesia by a Belgian agronomist, M. Adrien Hallet. In the year 1911, a Frenchman, Henri Fauconnier secured some palm seeds to be planted in Rantau Panjang, Selangor, Malaysia [1].

In 1974, palm oil refineries were introduced throughout Malaysia, causing the country to undergo an industrial revolution in palm oil processing. Alongside the financial aid and plots of land from the government being given to interested entrepreneurs in the palm oil business, the palm oil industry in Malaysia began to flourish at an exponential rate.

In a span of 2 years, 15 palm oil refineries were already up and running in Malaysia, sending the country straight to the top as being one of the world's leading palm oil exporters. A variety of methods with the likes of mechanical extraction, microemulsion, solvent extraction and also traditional methods can be used for the extraction of palm oil and palm kernel oil [2-4].

Seeing that the mechanical method of extraction is the most common and efficient way to obtain palm kernel oils without the addition of organic solvents or heating processes [5, 6]. This paper will revolve more around the mechanical extraction method of palm kernel oils which utilize a palm kernel screw press.

Harvested fresh fruit bunches must be processed within the same day to prevent a decline in the oil quality of the fruit [7]. Therefore, the mechanical method of extraction is the most prominent as it does the job at a rapid pace. The mechanical method of obtaining palm kernel oil is illustrated in Figure 1.

Firstly, the palm kernels are cleaned to avoid alien materials from decreasing the lifespan of the screw press. Then, the kernels are put into a grinder to form coarse kernel flakes that will be softened by steam before going into the screw press machine. The machine proceeds to crush the flakes and crude palm kernel oil is obtained alongside palm kernel

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cake which is a waste material that can be utilized as animal feedstock. The crude palm kernel oil goes through a filtering process to be refined into the end product which is palm kernel oil.

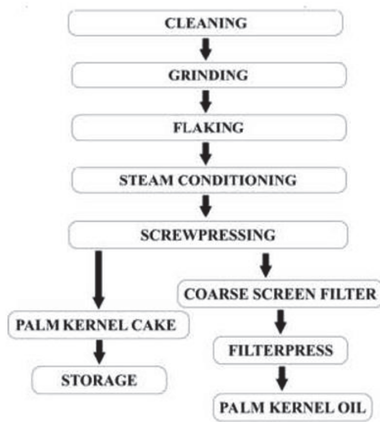

FIGURE 1. Palm kernel oil extraction and refining process [4]

Seeing that the screw press is the heart of the extraction process, its concept will be explained. The sole function of a screw press is to squeeze the palm kernel flakes among the travelling cones and the main screw to expel crude palm kernel oil [8]. An illustration of a palm kernel screw press can be seen in Figure 2.

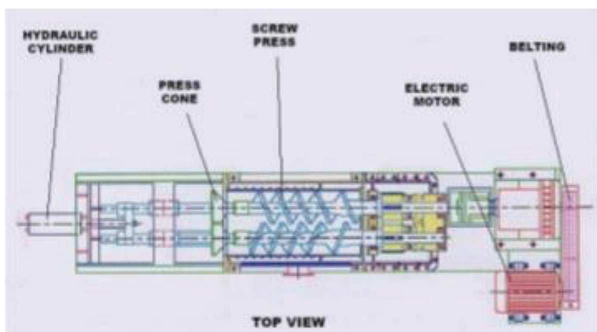

FIGURE 2. Palm kernel screw press [8]

The palm kernel screw press is set to run for 24 hours. Thus, this continuous usage of the screw press exposes it to the risk of wear and tear, thus needing maintenance to be done. Although a scheduled preventive maintenance can be carried out by the refinery owners, a majority of these machines are left to run past the date of maintenance to sustain a high net yield of palm kernel oil.

The effectiveness of the palm kernel screw press is crucial to enhancing the extraction of oil. An ineffective machine will cause a high loss in the yield of oil and also increase the maintenance cost of the machine. Thus, the objective of this project is to create a functioning prototype as seen in Figure 3 that is capable of collecting mass flow rate data of the palm kernel cake output from the screw press machine.

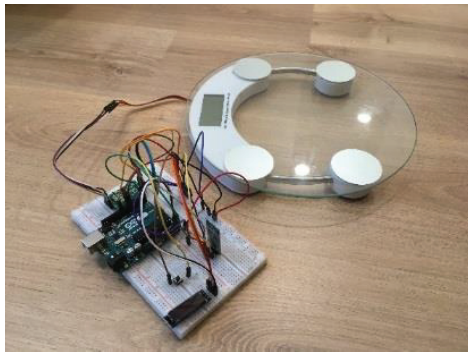

FIGURE 3. Data collection system prototype

The collected data can then be relayed across a wireless Bluetooth connection to either an Android device or computer which will allow untrained personnel to monitor and report when maintenance is due. Thus, optimizing the resources within the refinery and allowing workload to be better distributed.

METHODOLOGY

After reviewing literature and utilizing conceive techniques such as Brainstorming and Trimming to arrive to a specific plan on how to construct a functioning prototype of the system. The development of the fully functioning prototype relied on the application of specific electrical components and precise manufacturing of the system with reference to the flowchart in Figure 4.

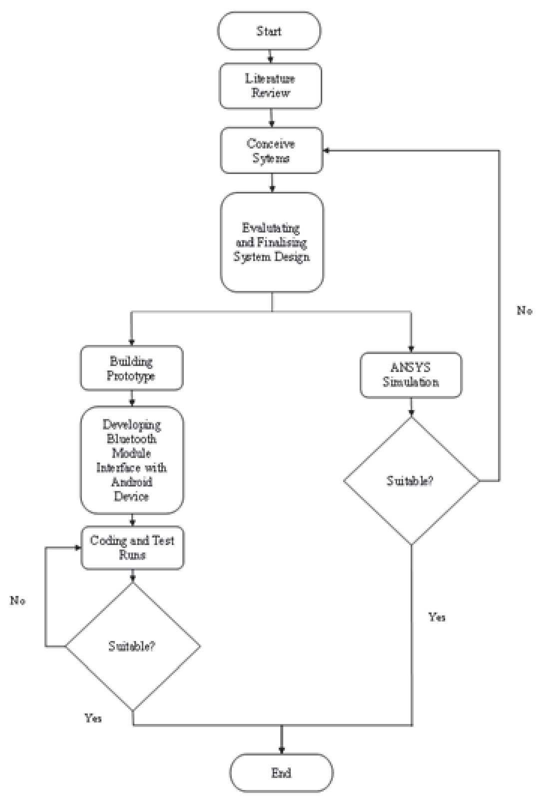

FIGURE 4. Research methodology flowchart

Electrical Components

Prior to the assembly of the prototype, a few core components must be analyzed and discussed as explained in the following subsections.

Wheatstone Bridge

The Wheatstone bridge is made up of 4 resistors arranged in two basic series-parallel connections with a difference between the ground and voltage supply terminals when the bridge is at a balanced state as seen in Figure 5. The Wheatstone bridge is most suitable to measure a small change in resistance, therefore making it applicable to measure resistance changes in a strain gauge [9].

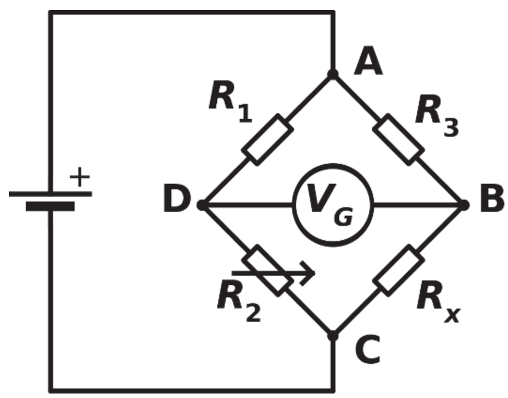

FIGURE 5. Wheatstone bridge schematic diagram [8]

It is known that the strain applied to the strain gauge is proportional to the resistance change as shown below by the equation:

$$\frac{\Delta R}{R_0} = k \times \varepsilon \tag{1}$$

The general equation for the ratio of the voltage output to voltage input, U_A / U_E can be expressed as:

$$\frac{U_A}{U_E} = \frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \equiv \frac{R_1 \times R_3 - R_2 \times R_4}{(R_1 + R_2)(R_3 + R_4)} \tag{2}$$

Based on Equation 2, in the case of a balanced bridge, where U_A / U_E is equal to zero:

$$\frac{R_1}{R_2} = \frac{R_4}{R_3} \tag{3}$$

If there were to be a discrepancy between the resistor values, the Wheatstone bridge will be detuned, causing the output voltage, U_A to be present in the equation. Together with an assumption that the difference in resistance, ΔR_i is lesser than the resistance R_i, the following equation is formed:

$$\frac{U_A}{U_E} = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right) \tag{4}$$

In a practical strain gauge situation, all resistors are supposed to contain the same nominal value to keep the changes relative to each individual bridge arm proportional to the variation relation to the voltage output. The nominal resistance between R_1 and R_4 or R_2 and R_3 are negligible. Therefore, it is safe to assume that $R_1 = R_2 = R_3 = R_4$ [10,11].

Substituting equation (1) in (4), it is found that:

$$\frac{U_A}{U_E} = \frac{k}{4}\left(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4\right) \tag{5}$$

In a nutshell, the Wheatstone bridge demonstrated the idea of a dissimilar measurement that is incredibly accurate. In many situations, the measurement of an unknown resistance is often related to measuring the effect of some form of physical phenomenon such as force, pressure, and temperature. This enables the Wheatstone bridge to indirectly measure those elements [12]. The Wheatstone bridge is crucial in the design of this prototype because the weighing scale is made up of 4 load cells arranged in a manner as seen in Figure 5. This ensured that constant mass readings will be seen from the weighing scale despite of where an object is placed on the weighing scale.

Voltage Dividers

A voltage divider, also known as a potential divider, is a linear passive circuit which gives out an output voltage a fraction from its input voltage. This is done by delegating the input voltage across components within the divider. A standard voltage divider consists of two resistors with a series connection. An input voltage is introduced across the pair of resistors while an output voltage is situated on the connection between the two resistors as seen in Figure 6 [13].

In a resistive divider, impedances Z_1 and Z_2 are entirely resistive. Therefore, $Z_i = R_i$ forming an equation:

$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$$

Resistive voltage dividers are used most of the time to produce a reference voltage or to decrease the voltage magnitude for it to be measured. A voltage divider can also be as a signal attenuator at low enough frequencies [14]. A relevant usage of a voltage divider for the project is to step-down voltage. The HC-05 Bluetooth Module required an input voltage of 5V to power up the system. However, the RX pin of the HC-05 could only function at 3.3V. Therefore, a voltage divider was introduced into the system in order to allow the HC-05 to function as intended and to protect the HC-05 from permanent damage.

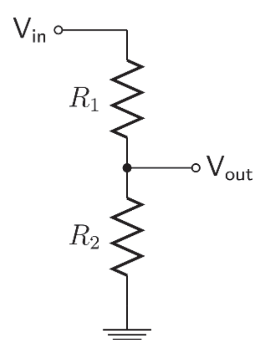

FIGURE 6. Resistive voltage divider [11]

System Layout

The materials used to build the prototype and the appropriate connections of each electrical component are shown below.

Materials:

- Weighing Scale
- HX711 Amplifier Module
- Soldering Iron
- Soldering Wire

- Arduino Uno
- OLED Display
- Push Button
- Jumper Wires (Male-to-Male and Female-to-Male Connection Ends)
- Breadboard
- HC-05 Bluetooth Module

The connections among components within a system are crucial in order to ensure that the system is able to operate as planned. Hence, Table 1 shows the connection between each pin on the PCB of the weighing scale and the HX711 Amplifying Module.

TABLE 1. Connections between the PCB and HX711 terminals

Terminal on the PCB	Terminal on the HX711
E+	E+
E-	E-
S+	A+
S-	A-

The connections showed in Table 2 on the other hand show the relationship between each electrical component within the data collection system with the Arduino Uno microcontroller. A full graphic of the assembly of electrical components within the system are also shown in Figure 7 to allow for a better visualization of the connections within the system.

TABLE 2. Connections of Electrical Components to the Arduino Uno

Component	Pin on the Arduino Uno
HC-05 Bluetooth Module	
VCC	5V
GND	GND
TXD	0 (RXD)
RXD	1 (TXD)
OLED Display	
VCC	5V
GND	GND
SDA	A4
SCL	A5
HX711 Amplifier Module	
VCC	5V
GND	GND
CLK	7
DAT	6
Push Button (Leg 1 is on the top left)	
Leg 1	9
Leg 3 (Clockwise from Leg 1)	GND

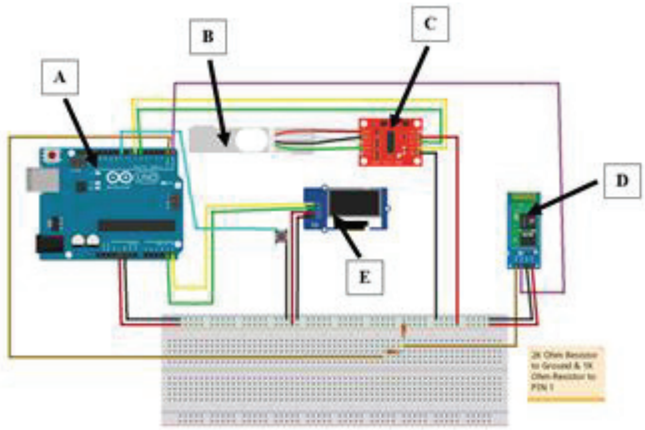

FIGURE 7. Graphic of full system assembly

Where,
A = Arduino Uno Microcontroller
B = Load Cell
C = HX711 Amplifier Module
D = HC-05 Bluetooth Module
E = OLED Display

Coding and Application Development

The coding of the system consists of programming the push button to zero the scale and also to set a starting point and cut off point for mass and time readings to be taken. For example, mass readings and time duration are started at 2 kg and cut off at 40 kg. Thus, the following equation will be utilized to calculate the mass flow rate of the palm kernel cake output:

$$Mass\ Flow\ Rate\ (kg.s^{-1}) = \frac{(40-2)kg}{(Cut\ off\ time - Starting\ time)\,s}$$

The mobile application developed using the MIT App Inventor functioned to establish a Bluetooth connection between the HC-05 and an Android device, notifying the user once the connection is established. Mass flow rate data calculated by the Arduino Uno is then displayed to the user once the cutoff point of 40 kg was triggered, sending an alert message combined with an alarm to prompt the user to check on the readings. Every reading generated is not only displayed on the Android application for the user to see but also collected and compiled in a Google Firebase server to make long term monitoring possible.

RESULTS AND DISCUSSION

Load Cell Calibration Test

The load cell within the weighing scale is first calibrated to ensure that legitimate results can be obtained from the experiment. A “Load Cell Calibration” code is introduced into the Arduino Uno to start the calibration process. Then a weight of known mass is placed onto the weighing scale to obtain the scale factor which goes by the formula:

$$Scale\ Factor = \frac{Mass\ Picked\ Up\ by\ Load\ Cell}{Known\ Mass\ (Actual\ Mass)}$$

The above formula is fairly simple to comprehend as it merely takes the mass reading picked up by the load cell and divides it by the mass of the known weight. Once the scale factor is found, mass readings picked up by the load cell will be aligned with the actual mass of the object due to this formula:

$$Actual\ Mass = Scale\ Factor\ \times Mass\ Picked\ Up\ by\ Load\ Cell$$

To carry out the calibration, a mass of 0.51 kg was used for the test. The test was repeated 200 times to obtain varying scale factors and an average of the 200 readings was used as the final scale factor. For the final scale factor of 17600, mass readings from weights of 0.510 kg, 1.020 kg, 2.039 kg, 5.099 kg, and 10.197 kg were noted down to obtain an average reading and percentage error of each mass as seen in Table 3. The percentage error formula is as follows [15]:

$$Percentage\ Error = \frac{|\ Average\ Mass - Actual\ Mass\ |}{Actual\ Mass} \times 100\%$$

Figure 8 was then plotted with reference to the values obtained in Table 3 to identify a trend within the percentage errors which will be interpreted later. Based on Figure 8, the percentage error experienced an almost exponential increase and is seen to reach a plateau at around the 10.197 kg mark. Overall, the highest percentage error seen in the graph is 5.18% and although it is a relatively small error, future steps must be taken the reduce such an error as accuracy is very important when it comes to the measurement of mass [16]. The load cell is seen to function the best at low mass values and perform sub optimally in higher mass values making the weighing scale overall functionable but more reliable when used to measure light masses.

TABLE 3. Table of comparison between actual mass, average mass and percentage error

Actual Mass (kg)	Average Mass (kg)	Percentage Error (%)
0.51	0.5135	0.69
1.02	1.0305	1.03
2.039	2.1145	3.70
5.099	5.3555	5.03
10.197	10.725	5.18

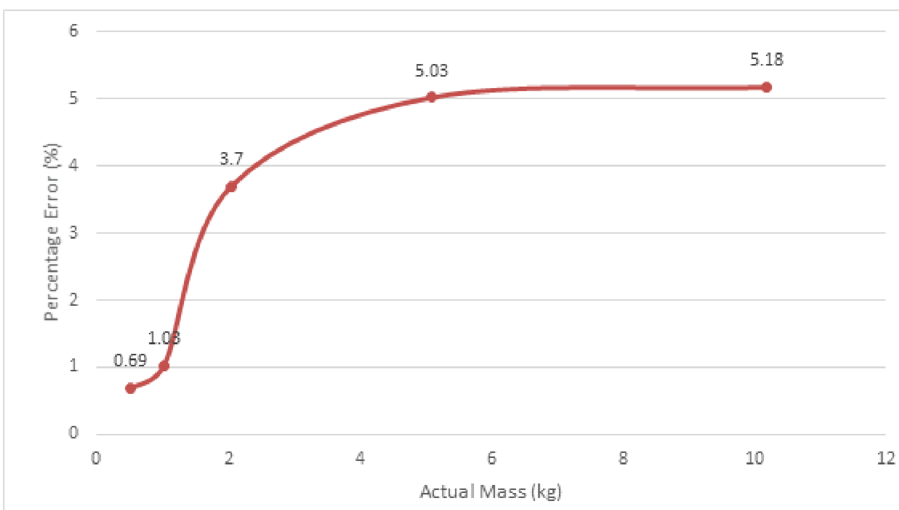

FIGURE 8. Graph of Percentage Error (%) Against Actual Mass (kg)

A manner to reduce the percentage errors seen in Table 3 would be to utilize load cells of a higher quality. This is because load cells are affected by non-linearity which is the maximum divergence of the load cell's calibration curve from a linear line. This deviation is measured from zero load to the point of the load cell's maximum rated capacity. Therefore, a better load cell would minimize the deflection of the load cell's calibration curve and thus, increasing the accuracy of the load cell [17].

Bluetooth Module and Arduino Uno Communication Interval Test

Before the test can be explained, it is crucial to have prior understanding of how the application operates. Thus, the steps to utilizing the application are shown below. Figure 9 provides a visual to how the mass flow rate data is displayed on the application and in Google Firebase live database.

Steps:

1. Startup the application
2. Click on the Bluetooth icon to begin establishing connection
3. Select device to establish a connection with
4. Wait for alert message and alarm to show up
5. Press "OK" to end the system.
6. Mass flow rate data will be sent to Google Firebase Live Database.

This test for the system involves simulating a real-life situation in which the system is supposed to operate in. Firstly, a bucket was placed on the weighing scale and the scale was zeroed by pressing on the push button. The MIT app was also accessed to on an Android phone and sand was poured at a steady rate into the bucket. The starting point and the cut-off point was set to 1 kg and 10 kg respectively in order to test the responsiveness of the whole system across a wide range of masses. When the sand reached the 10 kg mark, a sounding alarm along with an alert message was observed from the MIT app, mass flow rate readings were also seen on the app and through the Firebase Live server from the computer proving that the system was fully functioning as intended. The test was then repeated 4 more times and each time there was found to be no delay of communication between the Bluetooth Module and the Arduino Uno. The 5 out of 5 successful attempts was able to solidify the fact that the system was entirely running and capable to be used in a real-life palm kernel refinery [18].

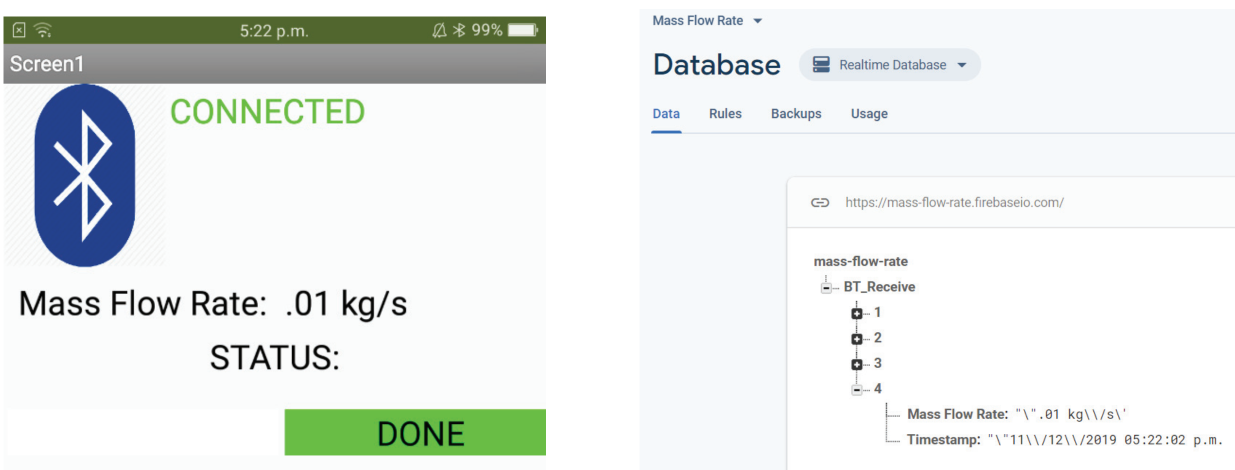

FIGURE 9. Mass flow rate data in the Android application (left) and Google Firebase (right)

Based on Table 4, the time interval of 1s was the most optimal choice. The time interval in this experiment refers to the gap in time where data is pulled by the Android application from the Arduino Uno. The reason for 1s being the top choice was because time intervals greater than 1 took too long to retrieve data from the Arduino. Although a time interval of lesser than 1 seemed like a good choice on paper, in a practical sense it was counterproductive to the project. The time interval of 0.1s was retrieving data so rapidly that the alarm and alert message were triggered repeatedly thus causing the Android application to not function as intended.

TABLE 4. Table of comparison between time intervals 10s, 5s, 1s, and 0.1s

Time Interval (s)	Result
10	Mass flow rate data was displayed very slowly through the Android application.
5	Mass flow rate data was still too slow for data to be reliable.
1	Mass flow rate data was displayed instantaneously upon reaching cut-off point.
0.1	Mass flow rate data was displayed at a very fast rate, causing the Android application to generate a series of same readings over a short period of time.

Ideal Mass Flow Rate of the Palm Kernel Screw Press

Since there are limited resources available to suggest the mass flow rate of the screw press machine, generic palm kernel screw press machine datasheets and also palm kernel harvest data were used to derive a rough approximation of the mass flow rate of a working screw press. A palm kernel will have to undergo two sequences of pressing in order to maximize the amount of crude kernel oil that is extracted out of the palm kernel. Therefore, two ideal mass flow rate readings will be deduced from the given data of a generic palm kernel screw press machine.

Table 5 presents the data collected from a journal source and also a generic screw press specification sheet which shows the processing capacity, performance, and palm kernel oil extraction amount for both pressing phases.

TABLE 5. Palm Kernel Screw Press Machine Data [4,19]

Capacity	
1st Pressing (Ton/Day)	20 - 22
2nd Pressing (Ton/Day)	15 - 16
Performance	
After 1st pressing	12% - 14% oil remain in the cake
After 2nd pressing	<7% oil remain in the cake
Palm Kernel Oil Extraction Amount	
17% of Palm Kernel mass being pressed	

Based on Table 5, the ideal mass flow rate during the first pressing will be between the maximum and minimum ranges of mass flow rate which is calculated by:

For 1st Pressing of 22 tonnes/day with 14% oil remaining in the cake (Maximum Value)

Since,

$$Theoretical\ Palm\ Kernel\ Cake\ Mass\ (\%) = 100 - 17 = 83\ \%$$

Therefore, the actual Palm Kernel Cake (PKC) mass after the 1st pressing is:

$$PKC\ Mass\ (tonnes) = 22(0.83 + 0.14) = 21.34\ tonnes$$

Finally, the mass flow rate reading is:

$$Mass\ Flow\ Rate\ (kg.s^{-1}) = \frac{21340\ kg}{(24 \times 60 \times 60)\ s} = 0.25\ kg.s^{-1}$$

The following calculations were repeated for:

- 1st Pressing of 20 tonnes/day with 12% oil remaining in the cake (Minimum Value)
- 2nd Pressing of 16 tonnes/day with 7% oil remaining in the cake (Maximum Value)
- 2nd Pressing of 15 tonnes/day with 0% oil remaining in the cake (Minimum Value)

Based on Table 6, the mass flow rate of a palm kernel screw press will be deemed as ideal as long as it is within the ranges of the ideal mass flow rate of the 1st and 2nd pressing. A higher mass flow rate than ideal would signify more oil remaining in the palm kernel cake while a lower than ideal mass flow rate would indicate that the machine is not producing output at an optimal rate. Hence this information can be applied to monitor the condition of the palm kernel screw press and to also locate the possible source of error within the screw press machine.

The significance to finding out the optimal mass flow rate ranges is that the data can be utilized within the system to serve as a benchmark for when maintenance is due. Thus, preserving the life cycle of the palm kernel screw press and preventing the wastage of financial resources.

TABLE 6. Maximum and Minimum Ideal Mass Flow Rate Values for 1st and 2nd Pressing

1st Pressing	
Condition	**Ideal Mass Flow Rate (kg/s)**
22 tonnes/day with 14% oil remaining in the cake	0.25 (Max)
20 tonnes/day with 12% oil remaining in the cake	0.22 (Min)
2nd Pressing	
Condition	**Ideal Mass Flow Rate (kg/s)**
16 tonnes/day with 7% oil remaining in the cake	0.17 (Max)
15 tonnes/day with 0% oil remaining in the cake	0.14 (Min)

CONCLUSION AND RECOMMENDATIONS

Palm oil production is a significant revenue earner for Malaysia as the country is the largest exporter of palm oil in the world with a maximum monthly export of 1.78 Mega Tonnes this year which is an increase of 7.8% of the maximum export of last year [20, 21]. However, little research has been done to existing body of knowledge that this field possesses as not many resources related to palm oil produce can be found. Thus, this project can serve as a reference for other researchers that are keen to contribute in this field. To-date no study has been made about implementing a data collection system for palm produce extraction. As proven in this study, the identification of the mass flow rate of oil extraction from a screw press alone is-able to determine the point where maintenance needs to be done and also assist in troubleshooting. The integration of more data collection units in addition to the existing mass flow rate system such as a volumetric flowrate system for the output of palm kernel oil and for the input of the fresh fruit bunch will be able to further enhance the troubleshooting capabilities of the screw press.

A few recommendations to improve the mass flow rate data collection system is to utilize a load cell with a nonlinearity specification that is ±0.018% of the rated output from the load cell. This enables the load cells to be more accurate in mass readings and sensitive towards changes in mass. A better load cell will also prolong the period before recalibration of the load cells have to be done again. Another recommendation is to use a stronger material when manufacturing the case of the weighing scale, preferably Aluminum 7075 since it is able to resist prolonged periods of loading which can reach a maximum load of 21.34 tonnes. This ensures that the system will have a greater life cycle before needing any replacement or repairs.

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