Journal of Sustainability Science and Management
Volume 14 *Number* 5, October 2019: 43-54

eISSN: 2672-7226

MATHEMATICAL MODELLING AND& SIMULATION OF THRESHER OPERATION IN PALM OIL MILL

SHANTI FARIDAH SALLEH*, SHAREENA SAREE., KHAIRUDDIN SANAULLAH., AFRASYAB KHAN, ROBIAH YUNUS, MARINI SAWAWI, NORDIANA RAJAEE, NORZAFIRAH AZRIAH MOHD FADZLI AND MOHAMMED HAJI ALHAJI

[1]*Faculty of Engineering, Universiti Malaysia Sarawak , 94300, Kota Samarahan, Sarawak, Malaysia.*

**Corresponding author: sshanti@unimas.my*

Abstract: The development of the palm oil mill has been on a downward trend recently due to world economic recession, the technological input for oil extraction is the factor that contributes to this production setback in the industry. Therefore, there a need to develop an advanced technology that will enable a spontaneous increase in the oil extraction rate (OER). This study is aimed at the development of the technological mode of operation for the thresher unit which has seldom been neglected over the years. Computational numerical analysis has been selected for this study focusing on the stickiness and centrifugal force of the thresher. The resistance force has been obtained through the calculation of all the loads obtains from the thresher body as well as from its revolution per minute (rpm). The calculation on the impact of the opposite force on the internal and external part of the thresher was conducted. It has proposed to verify gravity of forces of the fruit spikelet has on the thresher. The result from this study will be useful in the design of an efficient process for achieving high oil extraction rate in the palm oil mill Industry.

Keywords: Thresher, resultant force, palm oil mill, oil extraction rate (OER).

Introduction

The impact of Palm Oil Mill industry in Malaysian economy is in the positive growth over the past decades, this is evident from its major contribution to the gross domestic product (GDP) (Balu *et al*., 2018). The growth of this important sector is as a result of intense research and development of new processing technology used in the palm oil industry. As the innovation in this technology is continually developed, there is a need to intensify the production to meet the growing demand for palm oil in the international market. The optimization of basic unit operations equipment such as the thresher is vital to increase production. However, despite the efforts on the minimizing losses during thresher operation, the absence of thorough study of force analysis in the thresher that enables the attainment of increased production is still scarce (Sivasothy *et al*., 2005).

The need for innovative technologies to replace the traditional methods in the design of various unit operations especially the thresher in the Malaysia palm oil mill industry need further exploration as well as intense research. This innovation is aimed at to increase the Oil Extraction Rate (OER) which has been on the decline in recent times. It is equally important to note that an increase in OER will have a multiplier effect on the overall growth in Malaysia economy as well as meet the global demand for palm oil and its allied products. Malaysia palm oil mill industry has been encouraged to adopt any alternative methods to upgrade the product quality. Since the quality of palm oil produced largely depends on the threshing efficiency, it will be worthwhile to analyze optimise the performance of the thresher. The main function of the thresher is to detach the fruits from the bunch which is the first stage in the palm oil production process. The extraction efficiency is estimated from the losses at different stages of palm oil processing, and the processing losses are reported to be around 10% (Hassan *et al*., 2012).

Similarly, it has been reported that an improved sterilization system performance through the adjustment of temperature and pressure has improved palm oil production (Awalludin*et al*., 2015). But very little research has been done to increase the thresher efficiency. This is largely due to the complexity of using experimental to study the thresher operation. canaccount for losses encountered at the thresher unit. The most commonly used thresher machine across Malaysia is the rotary drum type. It depends on the physical size which can process capacity about 45-ton FFB per hour. The sterilized bunches are fed into the thresher drum, which rotates at a fixed speed of around 25 rpm. The drum is usually made up of small section channel bars or T shaped bars, arranged at equal distances around the outer circumference of the drum. The clearance between the bars is yet sufficient to allow the released fruit to drop through these gaps, while the empty bunch stalks remain inside the drum and are transported to the end of the drum opposite to the inlet side by means of bars fitted inside the drum at such an angle as to effect this movement of the bunches but sometimes the stickiness among fruit spikelet's and the drum material as well as between the fruits themselves leads to the blockage of these clearances. Hence, the study of this particular through efficient optimization tools will enhance improved understanding of the unit processes as well enhanced sustainable palm oil production that willincrease the demand for its use as a renewable energy resource in Malaysia and the world at large (Sumathi*et al*., 2008; Sulaiman*et al*., 2011).

This study provides an optimized approach for the improvement of the thresher oil mill drum design based on the numerical as well as an analytical approach. Hence, the objective of this study was to investigate the mathematical equation that could help in estimation of the adhesive forces in between the fruits and in between the fruit, fruit spikelets and the material of the thresher. Besides, a numerical study has been launched to investigate the centrifugal forces exerted on the walls of the thresher while it is rotating and loading with fruits. The adhesive force was quantified using analytical study whereas the centrifugal force was obtained by using ANSYS study based on a numerical approach.

Materials and Methods

This study is largely dependent on numerical programming based on established thresher design. Preliminary studies have been conducted to ascertain the viability of the mathematical equations used. The adhesiveforces, aswell as centrifugal forces within and outside the thresher unit, were also investigated. The modelling frameworks comprises of two phases: (1) the development of mathematical model developed from the initial investigations and (2) the simulation of the resultant forces with ANSYS software. Each phase also representshow the problem oil losses in the thresher can be avoided as identified and presented in the problem statement.

Thresher Design

The thresher design has been drawn using Solid Work® software in a 3D Dimension. The meshgeometers of the thresher obtained by using the ANSYS® 14.0 software. The thresher shape domains were drawn according to Serian Palm Oil mill "Technical drawing (Drawing Number: SEPOM/TS/11)" The main specifications for the thresher based on the preliminary investigation are shown in Table 1. Similarly, a finite element for the thresher to study the two types of palm fruit which are Dura and Tenera has been obtained. To obtained the resultant force, the effects of the type of fruits, the material of thresher, loading within and outside of the thresher and rotational velocity have been studied (Olaoye*et al*., 2011).

The main compartments have been divided into three different parts called thresher drum, cylinder bars and central rod. Each flow

Table 1: Specification of Existing Thresher Machine

Material	-	Structural Steel
External Diameter	mm	2200.0
Internal Diameter	mm	1980.0
Length	mm	4600.0
Capacity	m^3	7850
Density	kg/m^3	1450

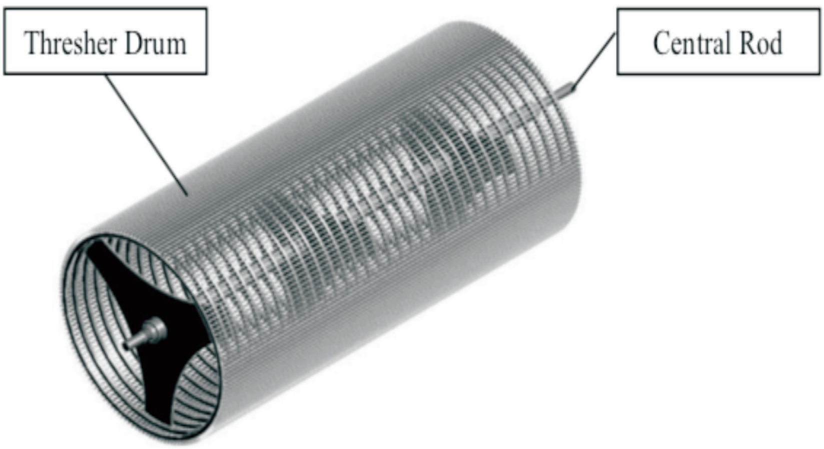

Figure 1: Thresher Geometry

domain is set to different boundary conditions concerning physical restraints. All flow domains were discretized with unstructured tetrahedral mesh to get the most accurate contact parts. The rotational velocity was set at the central rod of the thresher to rotate the whole thresher around its axial axis along the central rod. Besides, the central rod also used to support all the thresher parts. In this study, the fixed support applied at both ends of the central rod to fix the movement of the thresher along the axial direction. Since the drum is used to rotate the thresher, therefore both fixed supports needed to balance the thresher movement. Like in the real thrasher operational scenario, the palm fruit is stuck in between the cylinder bars of the thresher, therefore, the adhesive force calculated analytically has been exerted in the current study were chosen to distributed uniformly at the whole of the body of the drum.

Thresher Performance

The performance of the threshing machine can be evaluated by deriving associated equations described by the Food and Agricultural Organization, FAO (1994). Stripping Efficiency (SE), Threshing Efficiency (TE) and Cleaning Efficiency (CE):

Mathematical Approach

Fruits Type and Dimension

The two types of fruits that have been selected for this study are dura and "tenera" with theradius of ranging from 0.02256 m to 0.03014 m and 0.02597 m till 0.03336 m respectively. Other parameters in Table 1 are used to determine the stickinessas well as adhesive forces, and it can be deduced that these physical and mechanical properties can show the difference in the stickiness force value.

Physical and Mechanical Properties of Palm Fruits

Two physical parameters that will be useful in the design on thresher is the cracking force for both fruits and their mean pressure. Tenera required 1149 N average cracking force to break while dura is 2301N.Therefore, theTenera fruits tend to break easily compare to the Dura as which also can be defined by the mean pressure of Tenera 2.00N/mm^2 and dura 5.79 N/mm^2(Owolarafe *et al*., 2007).

Pull off Force between Two Oval Shapes

Another important parameter is the pull-off force and is known as the forces between two spheres and it relates to the adhesion work and radius of area contact as thus:

$$F_A = \frac{-3}{2}\pi r w \ until\ 2\pi R w \quad (1)$$

Where R is the radius of the spheres and ω is the work of adhesion. This equation obeys Derjaguin-Muller-Toporov (DMT) Theory. It also considers the effect of surface forces outside the contact area (Farshchi-Tabrizi*et al*., 2006). It has also been reported that states that the pull-off force lies between the values predicted by Equation (1)

Pull off Force between Solid and Liquid

There is also a pull-off force as a result of the adhesive force between solids and liquids within the thresher and it has been investigated in this study. It is a resultant force due to the spherical shape and liquid inside the plate (the oil palm at the surface of the thresher) together with fruit bunch stuck. The resultant adhesive force can be expressed in the equation below:

$$F = 4\pi R\gamma \quad (2)$$

While the magnitude of the work of adhesion and also the radius of the palm fruit has been determined using the equation

$$w = 2\gamma \quad (3)$$

Where is the work of adhesion and is the surface energy.

The present study revealed the individual amount of adhesive forces for both fruits, Dura and tenera,shown in Table 2.

ANSYS Workbench Set Up

For an effective presentation of this work, a detailed mechanical design drawing of the thresher has been obtained and this was conveniently converted to a prototype thresher drawing in solid work environment software while the numerical analysis has been accomplished using ANSYS software. The imported geometry into the ANSYS has been used to analyze the forces in a flow loop as shown in Figure 1:

In this case, ANSYS is a tool for numerical computations like other numerical methods such as finite element method, fluid-structure interactions and stress analysis, analysis for fluid dynamics, thermodynamics and analysis for the contact in machine elements. Static Structural study starts with completing engineering data, geometry transferring, physical set up and simulation study. At the beginning of this research, a general study on the thresher mechanical design drawing was studied. The condition of the thresher was designed based on the blueprint drawing collected. After that, mechanical drawing was converted to prototype using Solid Work Software and the numerical analysis using ANSYS has been accomplished. The force analysis in the imported geometry of the thresher has been done using the flow loop.

Figure 3 is depicted the simulation workflow for Ansys set up and it has three stages which start with pre-processing, processing and end with post-processing. The post-processing is the last step where the result will be analyzed and presented visually.

Pre-processing Stage

This stage involves the launching of the ANSYS workbench getaway to enable the application of the project schematic diagrams, engineering data analysis, thedesignof modelled as well as mechanical exploration. A structural analytical

Table 2: Values of Adhesive Forces of Dura and Tenera Types

Condition	FA (N)
In between (mild steel) solid and liquid surface for dura	0.001936
FA between (mild steel) solid and liquid surface for tenera	0.002129
FA between two ovals for dura	0.001936
FA between two ovals for tenera	0.2129

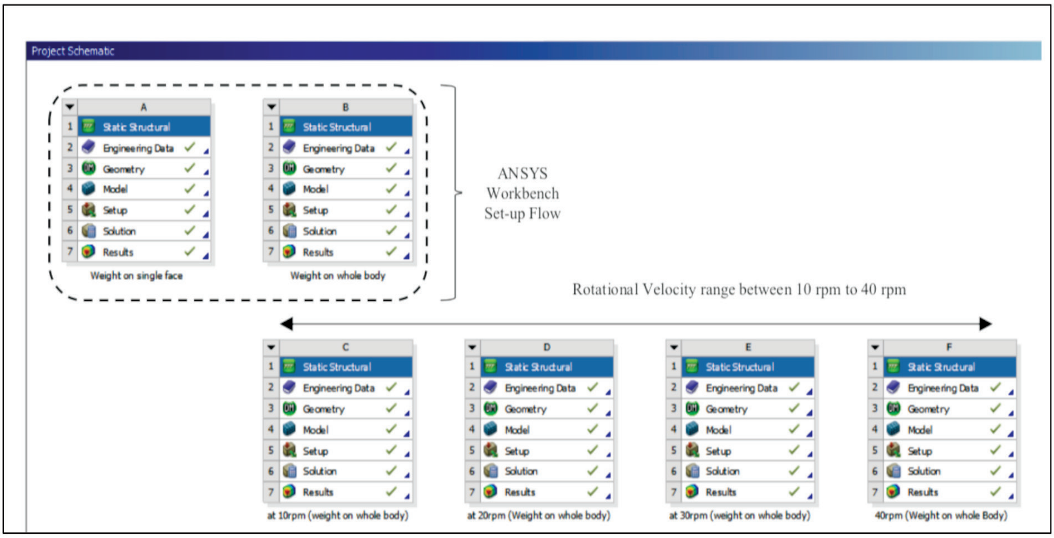

Figure 2: ANSYS Set up Workbench

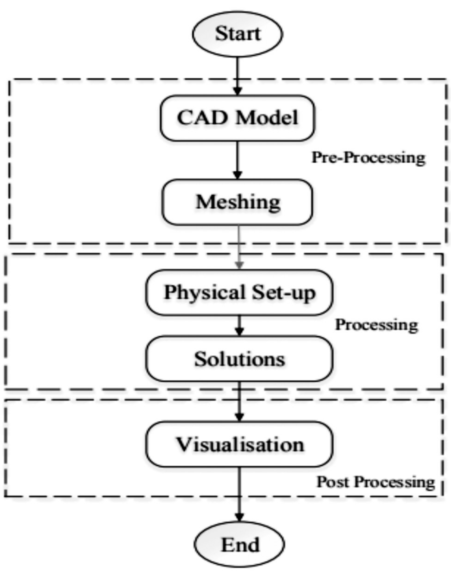

Figure 3: Simulation Workflow

system has been created to handle project schematics diagrams. The engineering data are sorted for incorporation into the project schematics. The Geometry cell once formed can be transferred via a Computer-aided design (CAD) model, in this case, a Solid Works used for the ANSYS Workbench simulations. The ANSYS workbench has three different compartments: thresher drum, cylinder bars,and central rod.

Processing Stage - Physical Setup

At this stage, the whole geometry obtained has been clamped at both ends with different rotational velocities through simulation. The rotational velocities are with a specified range of 10rpm to 40rpm. The load applied to thresher is usually a combination of the adhesive force and applied load at the surface of the thresher. Figure 4 and 5 show the graphic user interface geometry which is a summation of both the adhesive force and the weight of the fruit as well as the stickiness force within and outside of the thresher. The movement of the thresher allows the fruit bunches to move inside the thresher by the normal stress which is assumed to be exerted from the inside thresher to outward manners.

In this study, the total amount of force applied to the thresher is a sum of the load due to the fruits and material of the thresher itself and the type of fruits also varies the amount of the load. Figure 6 depicts the forces of resolution across the thresher after the simulation and this enables the investigation and analytical amount of the normal stress in x-direction and y-direction while the shear stress acting in z-direction acting along the body of the thresher. It is important to emphasize here that the simulation has been focused on variation in loading, material type, rpm and type of fruits and this determines the outward force exerted on the body of the thresher.

Processing Stage and Post-processing

At this stage, the physical set-up has been completed after the loads and supports are set-ups. As the simulation begins, it is assumed that all the loads associated with the thresher have been cut-off in the real world since there is going to be a boundary for the thresher model The first boundary condition applied only to the finite elements of the thresher mesh and are referred to as environmental conditions. The cutting surfaces of the model are called the boundary of the model. The choice of the boundary is arbitrary as long as we can specify the boundary conditions on all of the boundary surfaces. In the workbench, all conditions applying on the finite element mesh are called the environment conditions, which include boundary conditions as well as conditions that are not specified on the boundaries. The solution to the finite element model can be achieved through the simulation of the mechanical GUI (Graphical User Interface) in the ANSYS software. The number of nodes, number of elements and the number of steps will then determine how long the simulation will be completed. Once the simulation is completed, it can be visualized and the results are presented in a tabular form and can be plotted accordingly.

Results and Discussion

The Resultant Force Exerted by Varying Rpm and Loading for A Specific Type of Fruit

Case Study 1: A single fruit bunch (Theoretical treatment of problem-numerical approach)

In this case study, the impact of the manufacturing material of the thresher such as Stainless Steel, Structural Steel and Aluminium Alloy is studied based on the stickiness forces.The numerical part of the analysis involves the calculation of the centrifugal force exerted by the single spikelet on the walls of moving thresher. This has been done using ANSYS (Version 14.0). The centrifugal force has been obtained through the variation of the rotational velocity per minutes (rpm), types of fruits and the weight manufacturing material of the thresher. First of all the loads on the thresher have been varied using single fruit bunch of the same type. This involves more than 100 to 300 numbers of fruitlets from the bunch. The maximum normal stress exerted by these fruits is shown in table Table 3 and Figure 4. It can be seen that there is

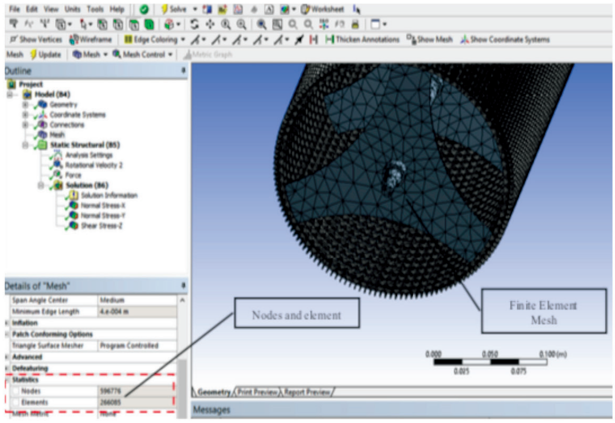

Figure 4: Meshing

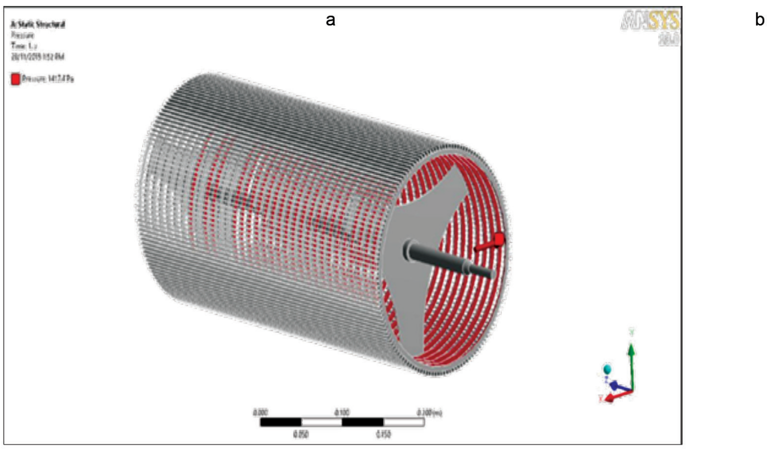

Figure 5: The Total Force acted on the Thresher Drum.

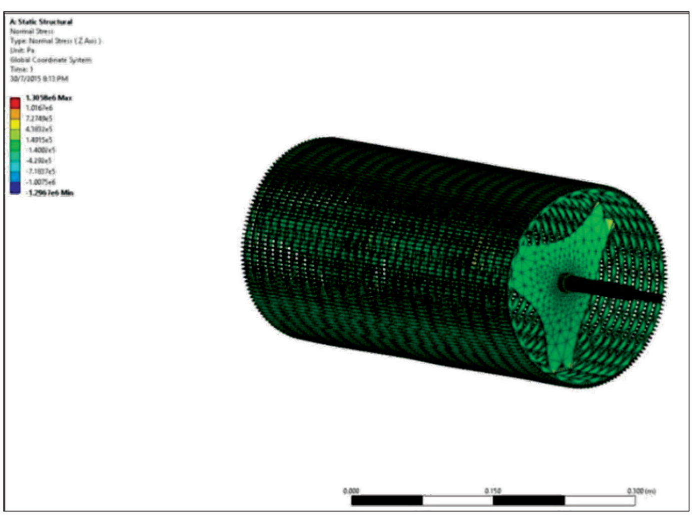

Figure 6: Resolution of Forces across the body of thresher after Simulation.

an acceptable high correlation between several fruitlets and the normal stress exerted on the thresher. The higher the number of fruitlets, the higher the amount of normal stress exerted on the thresher outwardly. The consequence of these is that the same amount of force will be requiredto avoid any fruits to be stuck. It has also been found that the amount of maximum normal stress for dura fruit varieties is lower thantenera fruit varieties.

The variations in normal stress are due to the differences in the radius of tenera fruit varieties(Verheye, 2010). Thus, this will bring a higher stickiness force for tenera fruits as compared to dura fruits. The resultant force is proportional to the resultant maximum normal stress which is required to remove the fruitlets acting within the thresher. The adhesive force between the fruits together as well as between the fruit and material of the thresher are calculated by the assistance of joint analytical and numerical study. For the numerical part, it helped to compute the normal stress after loading with varying number of fruit bunches. Besides, it also helped to calculate the centrifugal force acting any material body with a present of somebody inside the enclosure.

Case Study 2: A Multiple Fruit Bunches (Theoretical Treatment of Problem- Numerical Approach or Fruits varieties and Stainless Steel)

The effect of loading and rotational velocity, rpm (Scale-up for loading of fruit bunches) for Stainless Steel investigated.This case study has used the weight of fruit bunches varied from 10,000 kg to 40,000 kg as loading of fruit. From the weight, the total resultant force exerted by dura and tenera fruits can be calculated by varying the rotational velocity. The amount of loading is the total of the maximum adhesive force between the fruit bunches and between the fruit bunches and thresher material as well as weight exerted.Analysis of the force exerted

Table 3: The Normal Stress Exerted on the Thresher with Varying Number of Fruitlets.

Number of fruitlets	Normal Stress(Pa) Dura	Normal Stress(Pa) Tenera	Normal Stress (Pa) Mean
100	460.93	462.13	461.53
150	466.92	468.72	467.82
200	472.91	475.3	474.11
250	478.91	481.89	480.39
300	484.89	488.47	486.68

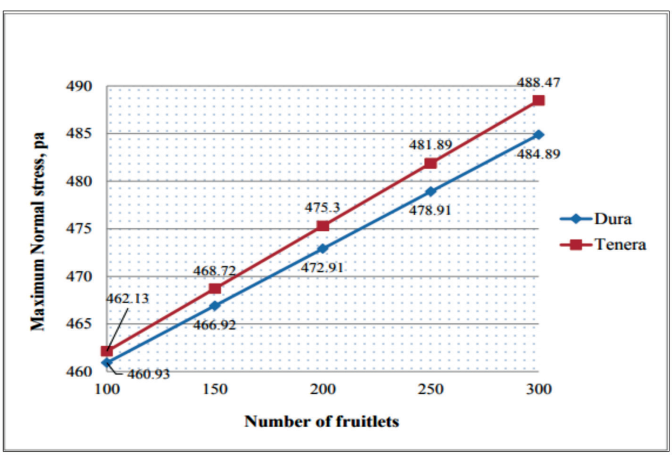

Figure 7: Normal Stress Exerted by the Both Fruitlets on the Body of Thresher (from inside towards outside)

by both fruitlet at varying rotational velocity (RPM) as well as variation in loading has been investigated. It has been found that minor effect cast by the variation of the rotational velocity observed on the force exerted by these fruitlets on the body of the thresher. On profiles yet this difference is not so much obvious but can be observed from the table which is used to draw these profiles.

The present profiles are about the maximum force exerted by the dura and tenera fruits on the walls of the thresher respectively. It has been observed that for both types the force is directly proportional increase to loading of fruit inside the thresher. At rpm varying from 10 to 40 and loading varying from 10 to 40 tonnes in each simulation step, the results have been shown in through Figure 8 and 9. The results showed that the tenera fruits exert slightly little larger force on the walls of the thresher.

Resultant Force Exerted by Varying the Type of Material used for Thresher Manufacturing Aluminium Alloy with Dura Fruits & Tenera Fruits

The displayed profiles have shown the result for the force by using an aluminium alloy for thresher material. The profiles were also obtained at different rotational velocity and loading. The variation for the forces is depicted in figure 10 and 11 for Dura and Tenera respectively.

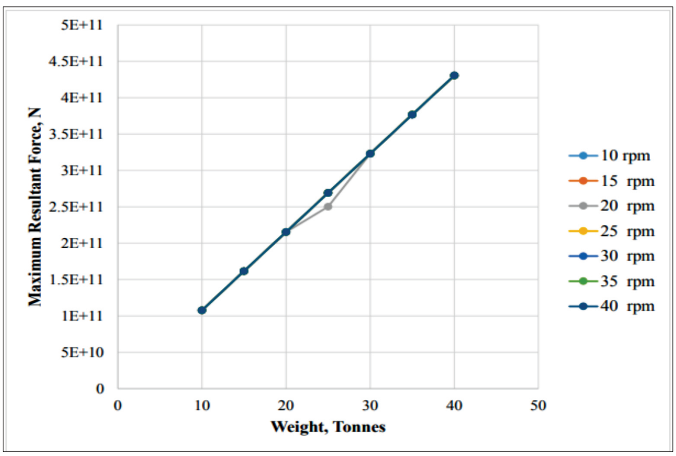

Figure 8: Dura fruitlet using stainless steel.

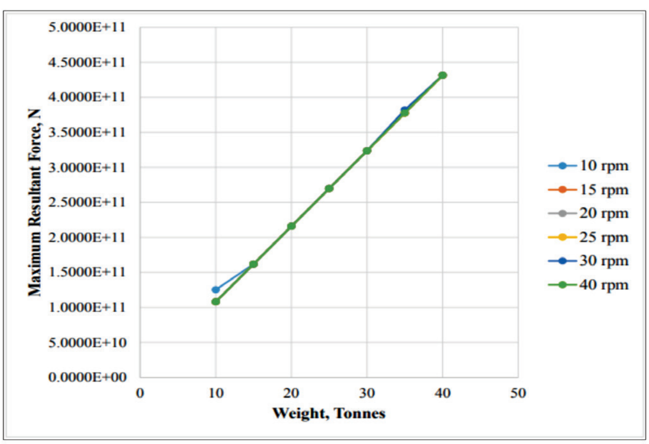

Figure 9: Tenera fruitlet using stainless steel.

Structural Steel Dura Fruits & Tenera Fruits

The displayed profiles have shown the result for the force by using structural steel for thresher material. The profiles were also obtained at different rotational velocity and loading. The variation for the forces is depicted in figure 12 and 13 for Dura and Tenera respectively.

Based on the profiles, the material of the thresher does not give significant impact to resultant force but only to rotational velocity and loading, one of the factors is the force is exerted from the body to the outward and not necessarily form material on the fruit surface/body.

Conclusion

It can be concluded that the resultant analysis of thresher design is depended on the external force and this force must be applied from within and outside of the thresher. A maximum force must also be selected during the operation and this must be summed up with the mechanical assemblage of the manufacturing parts of the thresher. To achieve a safer operation of the thresher, it is vital to remove all any interaction between human and the thresher. These measures will reduce the possibility of the fruit's stickiness into the thresher machine. Similarly, a self-cleaning device can also be installed in the

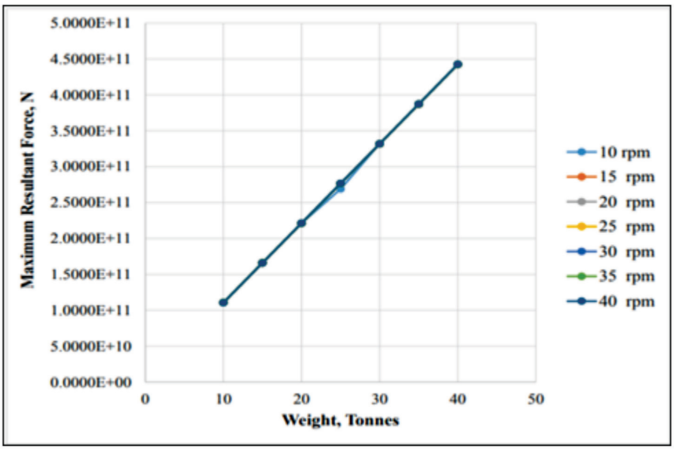

Figure 10: Graph of Dura Varieties using Aluminium Alloy.

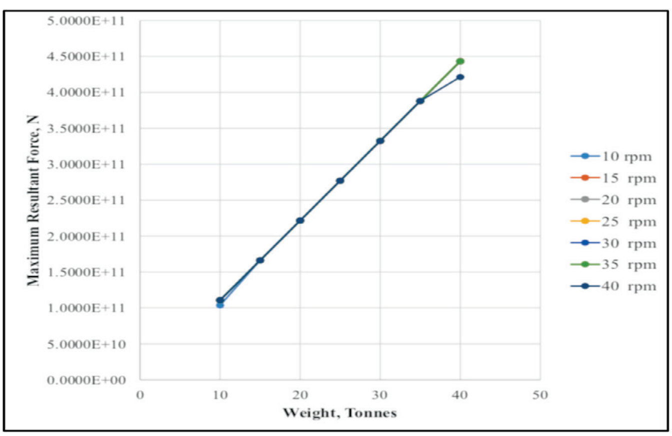

Figure 11: Graph of Tenera Varieties using Aluminium Alloy.

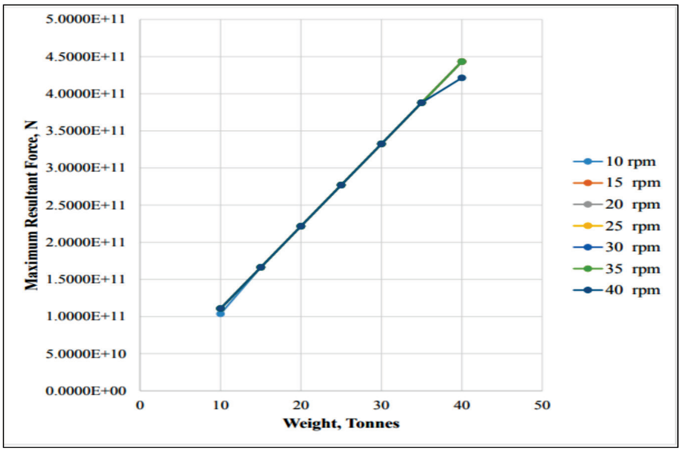

Figure 12: Dura Fruit using Structural Steel.

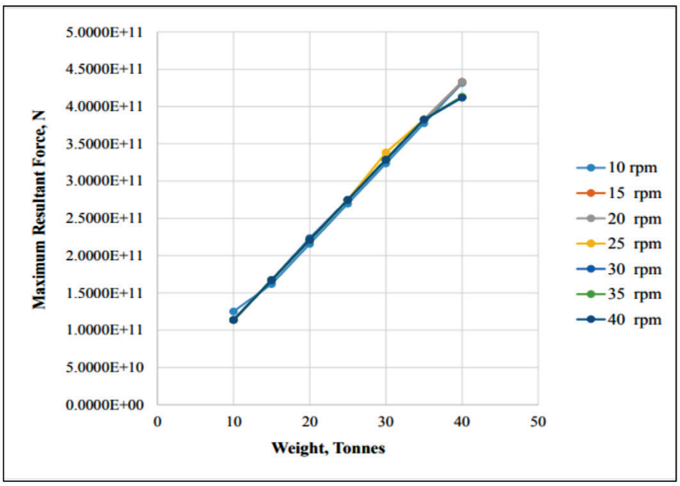

Figure 13: Tenera Fruit using Structural Steel.

thresher machine to reduce human interference. The task of self-cleaning has been accomplished by proposing a series of the tooth that should be inserted into the main thresher drum externally in a row. an automatic tooth insertion mechanism has been defined in which tooth of some flexible material mounted on a solid round rod will be inserted into the main thresher by the up and downward movement of a solid vertical rod. This rod is fixed on a fixture and is capable to move up and down with the help of a compressed of elastic spring. These modifications have not yet been addressed in the current study but for the future study, these modifications will help us to improve the performance of the thresher. With all these measures , oil extraction can be increased to meet the global demand for palm oil in the future.

Acknowledgements

This work is part of the MyRA (Special Short Term Grant) with grant number, F02/SpSTG/1387/16/29 which is the financial support in completing the research.

References

Awalludin, M. F., Sulaiman, O., Hashim, R., & Nadhari, W. N. A. W. (2015). An overview of the oil palm industry in Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. *Renewable and Sustainable Energy Reviews*, 50: 1469-1484.

Balu, N., Azman, I., Norfadilah, H., Nazlin, I., Dayang, N. S., Nik Abdullah, N. I., Noraida, O., Kamalrudin, M. S., Nur Ain, M. H., & Kushair. (2018). Malaysia: 100 Years of resilient palm oil economic performance. *Journal of Oil Palm Research*, 30: 13-25.

Farshchi-Tabrizi, M., Kappl, M., Cheng, Y., Gutmann, J., & Butt, H. J. (2006). On the adhesion between fine particles and nanocontacts: An atomic force microscope study. *Langmuir: The ACS Journal of Surfaces and Colloids*, 22(5): 2171-2184.

Hassan, A., Alias, H., Sabtu, M., Menon, N. R., Muhammad, N. H., Halim, R. M., & Ab Rahman, Z. (2012). Improving mill oil extraction rate under the Malaysian National Key Economic Area. *Palm Oil Engineering Bulletin,* 103:32-47.

Olaoye, J. O. (2004). *An Analytical Modelling of the Performance of Tooth Peg Grain Crop Thresher.* Doctoral theses, Department of Agricultural Engineering and Bio-systems, University of Ilorin, Ilorin, Nigeria.

Olaoye, J. O., Oni, K. C., & Olaoye, M. O. (2011). Computer applications for selecting operating parameters in a stationary grain crop thresher. *Journal of Agricultural Technonogy*, 7(1): 39-56.

Owolarafe, O. K., Faborode, M. O., & Olabige, M. O. (2007). Physical and mechanical properties of two varieties of fresh oil palm fruit. *Journal of Food Engineering*, 78: 1228-1232.

Sivasothy, K., Halim, R. M., & Basiron, Y. (2005). A new system for continuous sterilization of oil palm fresh fruit bunches. *Journal of Oil Palm Research*, 17(12): 145-151.

Sulaiman, F., Abdullah. N., Gerhauser, H., & Shariff, A. (2011). An outlook of Malaysian energy, oil palm industry and its utilization of wastes as useful resources. *Biomass and Bioenergy*, 35(9): 3775-3786.

Sumathi, S., Chai, S. P., & Mohamed, A. R. (2008). Utilization of oil palm as a source of renewable energy in Malaysia. *Renewable and Sustainable Energy Reviews*, 12(9): 2404-2421.

Verheye, W. (2010). Growth and production of oil palm. In: W. Verheye (Eds.), *Land Use, LandCover and Soil Sciences. Encyclopedia of Life Support Systems (EOLSS)*, UNESCO-EOLSS Publishers,Oxford, UK.