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DESIGN OF A CRUSHING MECHANISM FOR A BIOMASS BRIQUETTING MACHINE

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CERTIFICATION OF APPROVAL

DESIGN OF A CRUSHING MECHANISM FOR A BIOMASS BRIQUETTING MACHINE

by

FIFIZY HAFIZ SAFIDIL

A project dissertation submitted to the

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Approved by,

____

(Chin Yee Sing)

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TRONOH, PERAK

December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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FIFIZY HAFIZ SAFIDIL

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ABSTRACT

The biomass obtained from the agricultural sector can be used as a source of biomass renewable energy, palm shell and fiber to be exact. In order to utilize the use of these biomasses in combustion to generate energy, it is necessary to produce a solid compacted form of biomass known as briquette. Apart from having higher calorific value compared to loose powder form, briquetted form of biomass also ease up the transportation and storage problems.

The raw biomass required to undergo three processes to form a briquette, namely, drying, crushing, and compaction. This project covers the crushing part, to design the crushing mechanism of a biomass briquetting machine. Using available lab-scaled crusher machine and United States Patent as references, new design of a crusher mechanism has been produced. The new concept is basically combining the US patent and lab-scaled designs, with the working parameters of the lab-scaled machine maintained.

The project then continued by generating engineering drawings for the design to fit in the lab-scaled dimensions. Then, materials selection analyses were conducted to determine suitable materials for the new design. Maintaining the original material for the cutter, Dc53, two new materials were selected: Stainless steel and Mild steel. The new materials had shown better mechanical properties compared to the original, and therefore, they are recommended to be use as the base materials for few parts of the crushing mechanism.

CHAPTER 1

INTRODUCTION

1.1 Project Background

Malaysia palm oil industry has developed vastly in the past few decades where 38.5 million tonnes of palm oil has been produced on 5.65 million hectares of land in year 2007 (Malaysian Palm Oil Council, 2007). Currently positioned itself as the world's second largest producer and exporter of palm oil after surpassed by Indonesia in year 2006, Malaysia is still maintaining its position as one of the world's leading countries in the production of palm oil (United States Department of Agriculture, 2007).

Nonetheless, the industry has also generated enormous amounts of palm biomass which mainly produced from milling and crushing palm kernel. The types and amounts of the palm biomass generated in year 2005 are tabulated in Table 1. Generally, most of these biomass can be used as combustion fuels. Currently, the shell and fiber are the main sources of energy in palm oil mills. These fuels are burnt in boiler to produce steam for electricity generation to be used in the milling process.

Table 1: Palm biomass generated in year 2005

Biomass	**Quantity,** million tonnes	**Moisture Content,** %	**Calorific Value,** kJ/kg	**Main uses**
Fiber	9.66	37.00	19068	Fuel
Shell	5.20	12.00	20108	Fuel
Empty Fruit Bunches (EFB)	17.08	67.00	18838	Mulch
Palm Kernel Expeller (PKE)	2.11	3.00	18900	Animal Feed

Source: Science Publications, 2008

1.2 Problem Statement

Problems exist to transport and store these palm biomass in the loose form from the biomass source to the power plant. In order to utilize the resource and develop its usage as combustion fuel in a diverse industries and applications, raw palm oil biomass should be treated and upgraded into uniform and useful fuel. Therefore, it is necessary to design a system that enables palm biomass in the loose form to be compacted into a uniform solid fuel called briquette.

1.3 Objectives and Scope of Study

Basically this project covers few areas of engineering, energy and manufacturing being the majors. Energy concept is applied to understand the foundation of renewable energy as well as energy conversion of the palm biomass into combustion fuel. On the other hand, manufacturing understanding is needed in materials selection process and to come up with the system design in detailed engineering drawings. Apart from that, material selection analysis also required to determine the suitable materials to construct the machine.

The clear objectives of this project are listed as the following:

1. To design a crushing mechanism of a biomass briquetting machine.
2. To generate engineering detailed drawings.
3. To perform materials selection analyses.

CHAPTER 2

LITERATURE REVIEW

Practically used in China and southern of India to replace the fossil fuels such as oil and coals, palm biomass briquette is becoming a promising alternative and renewable energy which should be adapted to our country. Despite the palm biomass briquetting technology is spreading steadily among the developing countries, Malaysia is yet to have the machine that capable of producing the biomass briquette, which is the very reason why this project initiated.

Shown in Fig. 1 is the typical type of biomass briquetting machine available in the current market, India.

Fig. 1: A typical biomass briquetting machine
(source: Advance Hydrau-Tech Pvt.Ltd., 2009)

Basically, there are three major processes involve in a biomass briquetting system, namely drying, crushing, and compressing. Each of these processes has their own mechanism and they are usually connected by conveyer belts which used to pass on the output from the first process to the input for second process, and so on, as shown in Fig. 2.

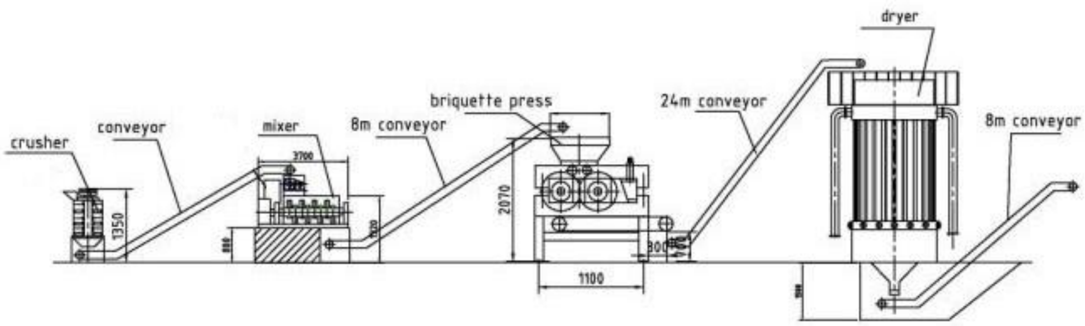

Fig. 2: Briquetting process
(source: Anyang General International Co., Ltd., 2009)

As stated before, there are three major processes will be engaged in a biomass briquetting system. Drying part is basically a process where the biomass, palm fiber and shell to be exact, will be heated up 105^{o}C to remove the excessive moisture contained in the biomass to an optimum moisture content of ± 10%. It is important to establish the initial moisture content of the biomass feed so that the briquettes produced have moisture content greater than the equilibrium value, otherwise the briquettes may swell during storage and transportation and disintegrate when exposed to humid atmosphere conditions (Khamis Johan, 2004).

After the palm biomass properly dried into the optimum moisture content, these palm shell and fiber will undergo the crushing process to turn its rough and coarse form into a finer powdery form of 63μm to 500μm in size (Khamis Johan, 2004). Then, compression part will take place to compact the mixture of shell and fiber into briquettes of cylindrical shape having higher density and energy content.

CHAPTER 3

METHODOLOGY

3.1 Project Activities

As discussed before, the palm biomass briquetting machine consists of three major parts which known as drying, crushing and compressing. Due to the research time constraint as well as the complexity of each part, this project will only focus on the crushing part of the briquetting machine, preferably addressed as crushing mechanism.

Being involved in the design of briquetting machine, this project started with investigation and study on similar designs available in the market. Although there are quite a number of briquetting machines available in the market, only lab-scaled parts are available in Malaysia which limits the research conducted. Therefore, this project designs are generated based on the lab-scaled crushing machine available which will be developed into industrial-scaled machine.

After conducting some study and research on the lab-scaled crushing machine available, three designs were generated which having different arrangement of cutting tools (rollers). Each of these arrangements has their own pros and cons which will be discussed in the proceeding chapter, Chapter 4. To ensure the availability of the machine parts in market, the same dimensions for the crushing roller will be applied in designing the industrial-scale crushing mechanism.

After selecting the best out of the three designs generated, dimensions determination process has been carried out where the appropriate dimensions for the crushing mechanism were addressed so that the crusher will be able to cater greater capacity for industrial application. Upon completing the dimensions selection process, engineering drawings for the crushing mechanism were generated using AutoCAD 2007.

Subsequently the three designs were presented in a seminar and evaluated by examiners. After thorough evaluation, the examiners decided that the designs cannot be pursued due to lack of information to be referred to. Thus, the project was started back from market research where few United States (US) patents on crusher were found and only one is suitable to be used for this project, which will be discussed in Chapter 4. By using two base references, lab-scaled crusher and US patent, new engineering drawings has been generated which adopting the designs of the US patent into the available lab-scaled crusher.

The activities for this project can be summarized in Fig. 3 where the processes have been carried out two times, one for the three preliminary designs which were decided cannot be pursued and the other for the design that adopting US patent crusher. The specific milestones for each activity starting from Final Year Project I to Final Year Project II are shown in the Table 2 and Table 3.

Available crushing mechanism in market investigated and studied

Available market – China and India

⇩

Initial designs were generated:

1. Using only lab-scaled crusher as the reference – three designs
2. Adding US patent as another reference – final design

⇩

Dimensioning process:

1. Cutting chamber
2. Roller size
3. Cutter's angle of attack

⇩

Engineering drawings:

1. Body
2. Roller
3. Rod + Locker
4. Cutters – fixed and rotating

⇩

Materials selection analyses:

Four candidates selected

Dc53, Stainless steel, Gray cast Iron, Mild Steel

Fig. 3: Project activities

3.2 Project Milestones

Table 2: Project milestones – FYP I

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	**Selection of Project Topic**															
2	**Preliminary Research Work**															
	- Project Background															
	- Problem Statement															
	- Objectives and Scope of Study															
3	Submission of Preliminary Report				●											
4	**Project Work**															
	- Investigate and study similar designs															
	- System categorization into parts															
	- Analyzing of each parts															
5	**Submission of Progress Report**									●						
6	**Seminar**									●						
7	**Project Work continues**															
	- Parts analyzing con't															
	- Conceptual design of each part															
8	**Interim Report Final Draft preparation**															
9	**Submission of Interim Report Final Draft**															●
10	**Oral Presentation** (1 day during study week)									Study Week						

Table 3: Project milestones – FYP II

No	Detail/Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14	15
1	**Project work continued**							Mid-semester break									
	- market crushing design research	■	■														
	- three (3) preliminary designs generated			■	■												
2	**Submission of Progress Report 1**				0												
3	**Project work continues**																
	- study on the lab-scale dimensions					■	■										
	- industrial-scale research for larger capacity						■										
	- engineering detailed drawings						■		■	■	■	■	■	■	■		
4	**Submission of Progress Report 2**									0							
5	**Seminar**									0							
6	**Project work continues**																
	- US patent study									■	■	■					
	- Dimensioning and engineering drawings										■	■	■				
	- Materials selection													■	■		
7	**Poster Exhibition**												0				
8	**Submission of Dissestation Final Draft**															0	
9	**Oral Presentation** (one day during study week)																0
10	**Submission of Dissertation - Hard Bound** (7 days after oral presentation)																

0 Milestone ■ Process

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Preliminary Designs

As mentioned in the last chapter, this project is started by investigating and studying the design available in market while using the lab-scaled crushing machine as the foundation. In order to design a crushing mechanism for industrial capacity while retaining the roller dimensions, the number of roller will become the variable. For this project, it is decided that three rollers will be used for the crushing mechanism and other numbers will be considered as future improvement. Using three rollers as the crushing tools, three designs have been generated where each design has different rollers arrangement, shown in Fig. 4.

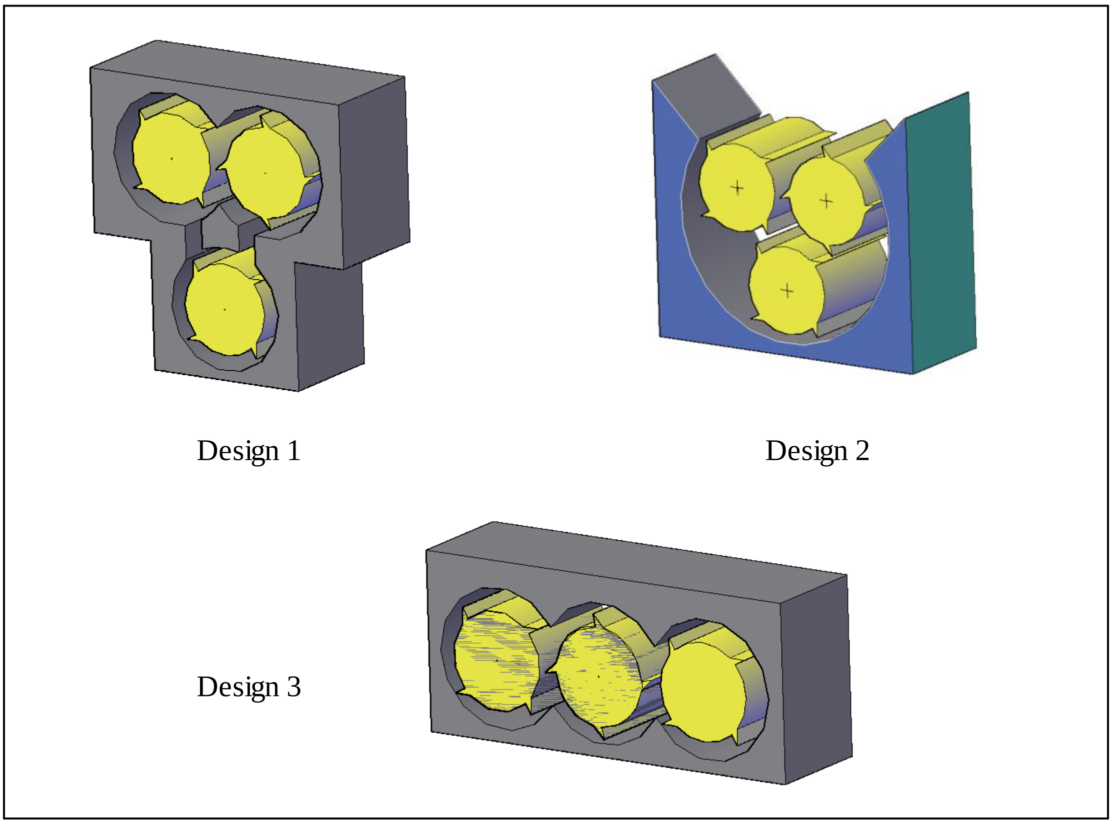

Fig. 4: Preliminary designs for crushing mechanism

Basically, there are only two criteria used in selecting the best out of the three designs: time consumption and output roughness of the premixed materials, palm shell to fiber ratio of 60:40 (Chin Y.S, 2008). For design 1, there are two stages of crushing available, 2 rollers for the first stage and 1 roller for the second stage. The palm shell and fiber will undergo the first stage which crushes the biomass into intermediate powdery form, followed by second stage to produce finer powder. In term of time, design 1 operates at the longest time among the designs but it produces the finest output.

Differs from design 1, design 2 only has 1 stage of crushing which uses three rollers at the same time. This design is a regular design which consumes moderate operating time and moderate output roughness produced. The last design is design 3, operates 3 rollers in parallel. Having rollers arranged in parallel make it possible for this design to accommodates larger capacity of input at a time compared to design 1 and design 2. In term of the output, moderate roughness of powder will be produced. The features for each design can be summarized in Table 4.

Table 4: Features for preliminary designs

Design	Time Consumption	Output roughness	Remarks
1	Longest	Finest powder	Two stages (1st two rollers, 2nd one roller)
2	Moderate	Moderate	Normal arrangement
3	Shortest	Moderate	Parallel arrangement of rollers

Based on the two selection criteria, time consumption and output roughness, the best design which suitable to be developed is Design 3. Design 3 occupies the shortest operating time as it can receive bulky input at a time, thus lowering the production time. Although finest powder is preferred to produce a briquette, the roughness of the output can be adjusted by varying the speed of the rollers. Thus, moderate output roughness produced by Design 3 is not the main concern and still can be tolerated.

4.2 Preliminary Dimensions

Based on the research conducted on available design in the market, there are various sizes and shapes of crushing machines having dimensions ranging from 4' x 8' to 7.5' x 6'. For this project, the dimensions will be kept as small as possible yet capable of operating industrial-scale capacity and for the time being, the exact dimensions are not decided yet until the whole crushing mechanism are in place.

Table 5 shows the technical specifications for the lab-scaled crusher which is being studied as the reference for this project. Based on the preliminary designs result discussed in the earlier part, Design 3 has the most suitable arrangement of rollers to be applied for this project where three rollers will be placed in a parallel position inside a cutting chamber. As the same roller will be used for the industrial-scale crusher, the width and height of the cutting chamber will be maintained whereas the length will be different as more roller used. The dimension of 160mm x 140mm for the lab-scaled cutting chamber has been changed to 360mm x 140mm for the industrial application, shown in Fig. 5 and Fig. 6.

Table 5: Specifications of Lab-scaled Crusher

Specifications	Value
Motor power (kw)	1.5~2.2
Motor speed (rpm)	190~195
Cutting chamber (mm)	160 x 140
Max. Capacity (kg/hour)	25

Source: Shini Plastic Technologies Inc, 2010

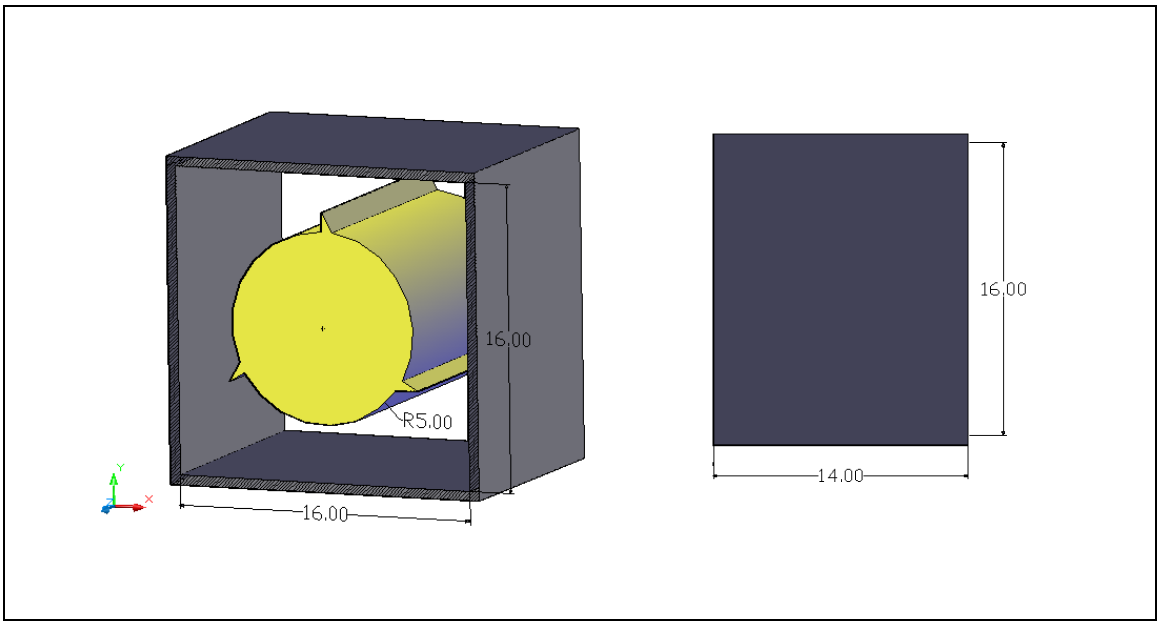

Fig 5: Lab-scaled cutting chamber dimensions

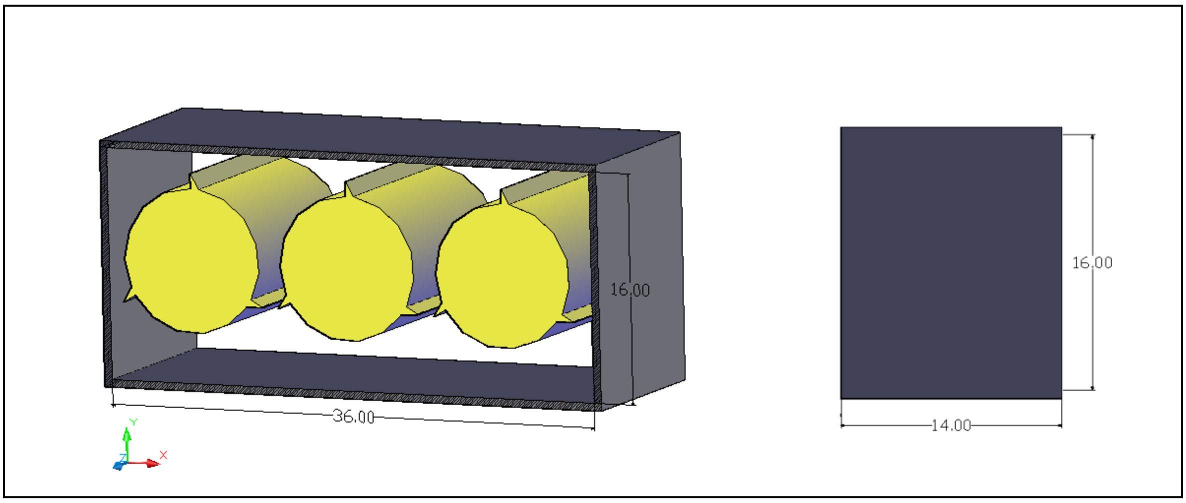

Fig 6: Industrial-scaled cutting chamber dimensions

As discussed in Chapter 3, these three designs had underwent the evaluation process by the examiners and it turned out that the process cannot be continued as insufficient information exist for the suggested the suggested designs. Thus, market research process was carried out once again to seek for crusher patent which can be adapted to the available lab-scaled crusher to generated new crusher mechanism. Few patents were accessed and the best patent which shows similar working process with the lab-scaled crusher is shown in Fig. 7 below.

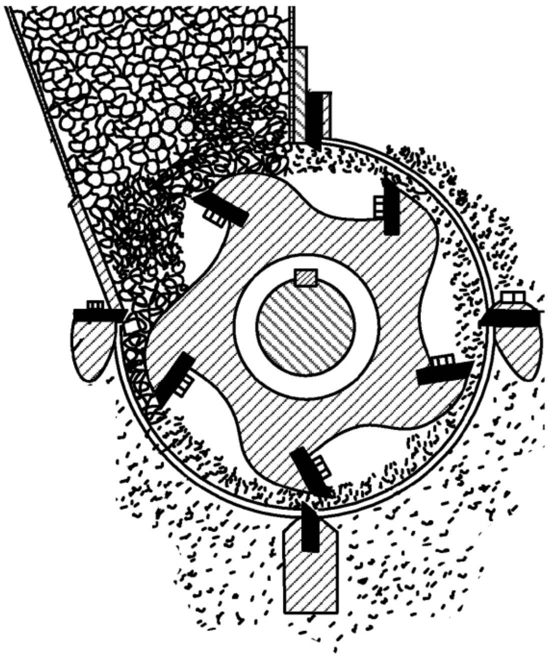

Fig. 7: US patent crusher - US 2009/0286295 A1
(source: Patent Application Publication, 2009)

Using the US patent crushing mechanism and lab-scaled crusher dimensions, new designs were generated which can be divided into four parts: body, rod and locker, roller, and cutter – fixed and rotating. Apart from changing the dimensions and the number of cutter of the US patent to match the lab-scaled requirements, the materials for the new design were also changed through the materials selection process which will be discussed shortly

4.3 Final Design and Dimensions

The final design of the crusher mechanism can be divided into four parts, body, rod and locker, roller, and cutters as shown in Fig. 8, Fig.9, Fig. 10, and Fig. 11, respectively.

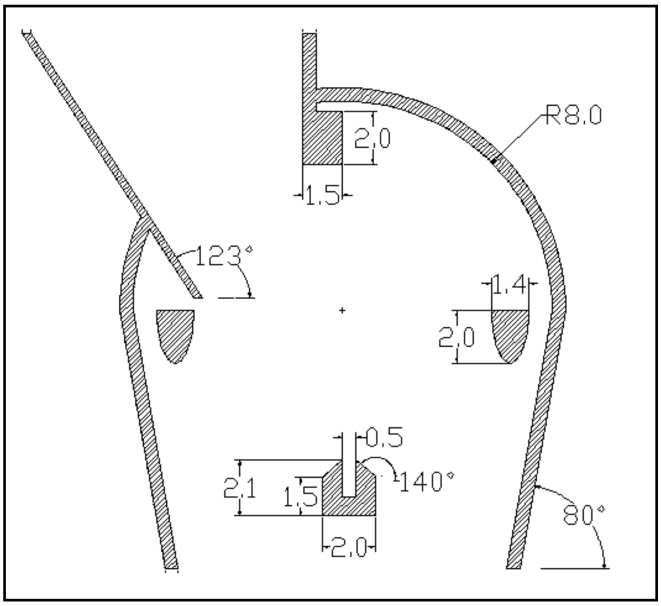

Fig. 8: Body

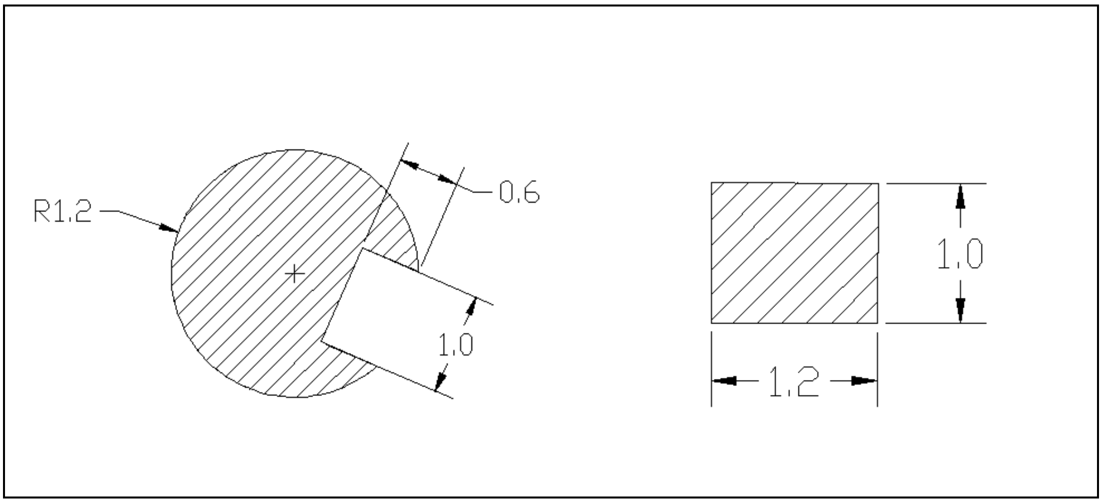

Fig. 9: Rod and Locker

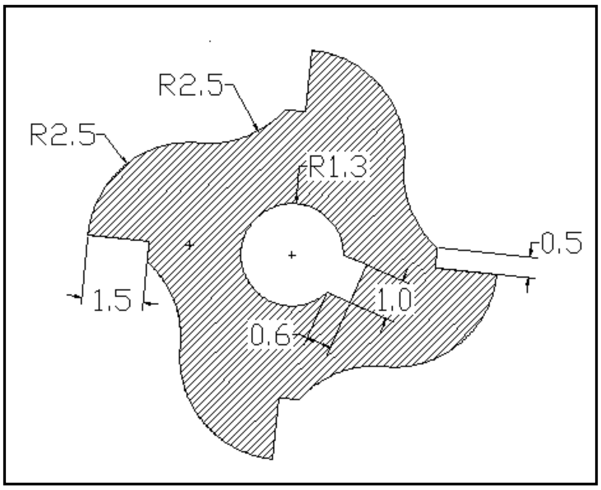

Fig. 10: Roller

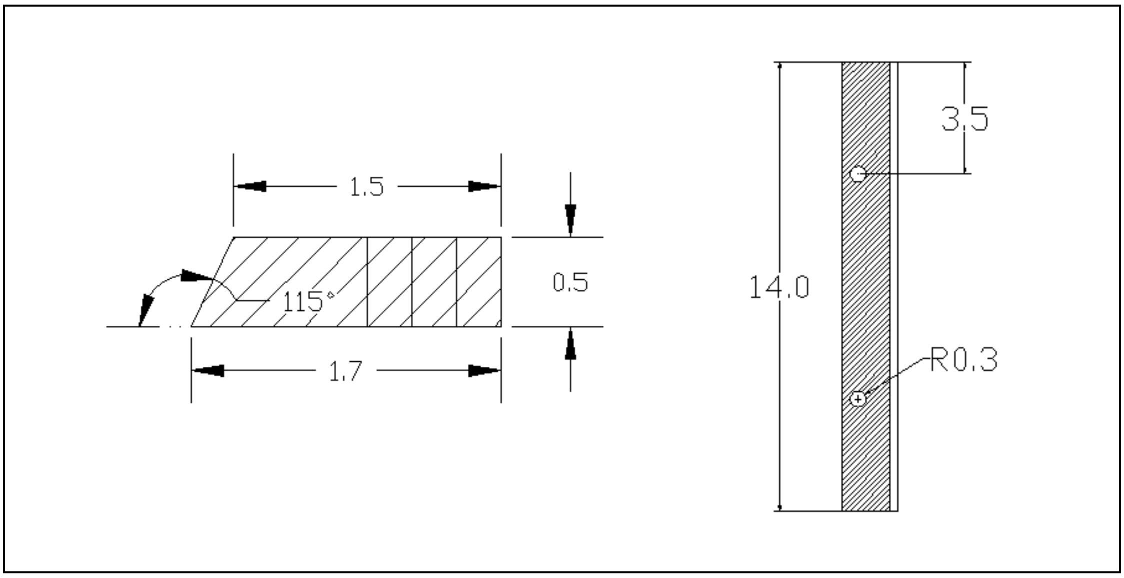

Fig. 11: Cutter

Fig. 12 and Fig. 13 below show all four parts of the crusher mechanism which have been assembled into one mechanism, in the hatched-view and isometric view, respectively.

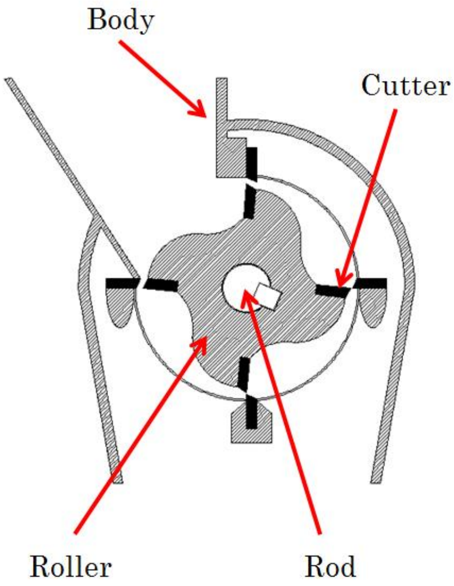

Fig. 12: Hatched-view of assembled crusher mechanism

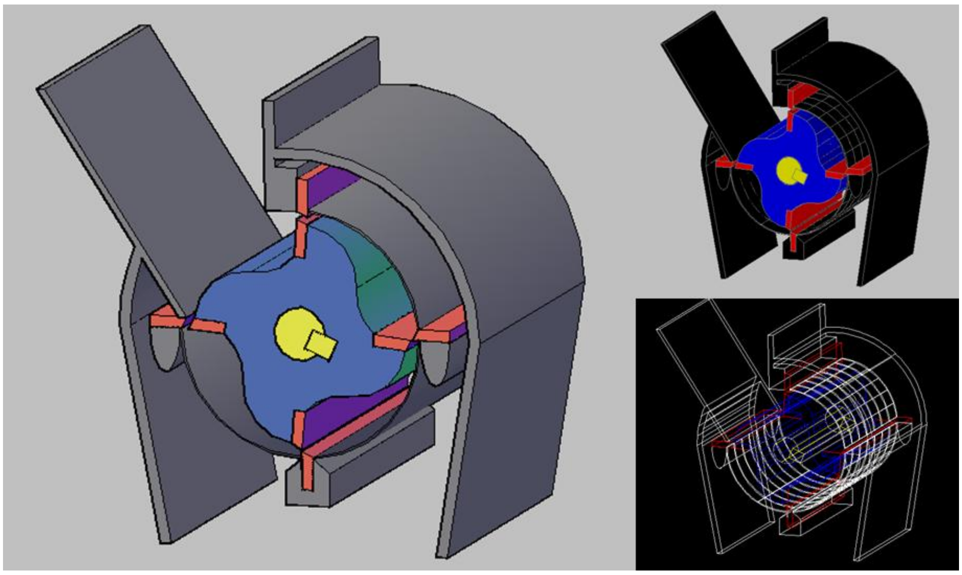

Fig. 13: Isometric view of crushing mechanism

Fig. 14 below shows the exploded-view of the crushing mechanism with its respective four parts:

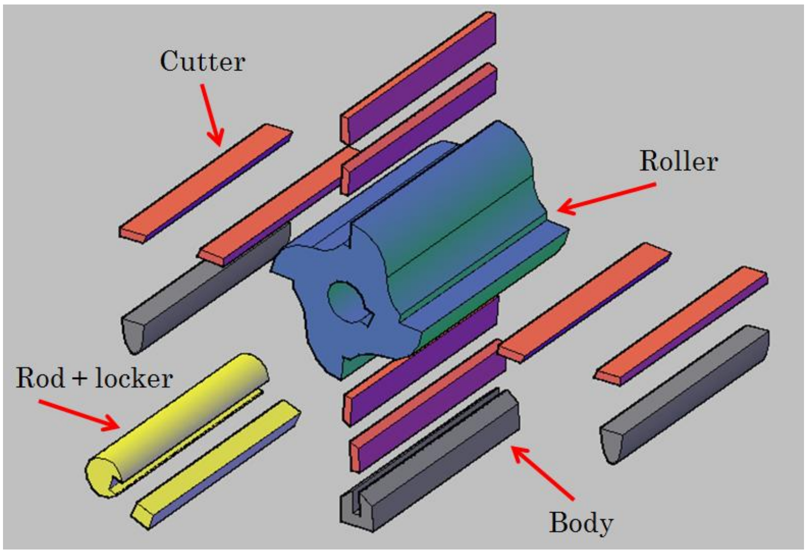

Fig. 14: Exploded-view of crusher mechanism

4.4 Parts' functions

The most critical parts are the rod and locker which located at the center of rotation. A motor which supplies power is connected to one end of the rod through belt and gears which will rotate the rod. The locker which located between the rod and roller is used to move the roller as the rod rotates, thus provides rotational force. It is a common application in the industry that one locker is sufficient to deliver the power from a rod to a roller as it is difficult to produce the exact same dimension of two lockers that will deliver equal force; one of it will experience higher force that the other and need to be replaced.

Replacing one new locker can be done but the other will fail anytime soon as it is weaker than the new one, while replacing both lockers whenever one failed is costly. These are the reasons why it is common in the industry to use only one locker instead or more, as the repair and maintenance works can be carried out easily if only one item needs to be monitored.

For the roller and the body, both parts do not have much significant roles in the crusher mechanism. The body is only use as the container to contain the palm fiber and shell while act as the cover for the machine, apart from providing base for fixed cutters, whereas the roller is used to deliver the rotational force from the rod to the rotating cutters. Although roller part is not as critical as the rod and locker parts, this part is also important because any failure occurs on the roller may jeopardize the rotating cutters condition – the rotating cutters may hit the fixed cutters if somehow the roller is broken. This is also one of the reasons why the roller is produced in such curvy-shape to prevent crack initiation and propagation in the roller which may leads to failure.

The last part which is the cutter can be categorized into two further parts, fixed cutter and rotating cutter. Fixed cutter is the cutter which is screwed onto the body part as its base, whereas rotating cutter is screwed onto the roller as its base, both types are having the same design and dimensions. In order to assess the forces that exist on the rotating cutter, calculations have been derived to determine the value of the rotational force acting on the cutter, which can be summarized as Fig. 16 below:

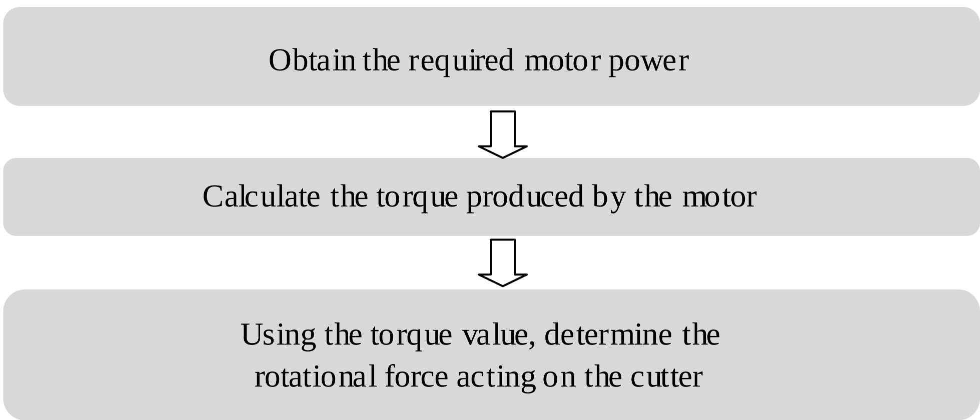

Fig. 15: Force calculation procedures

4.5 Acting Forces

To calculate the rotational force acting on the cutter, the specifications of the crusher's motor were obtained, shown in Table 6. Taking the tip of the cutter as the reference point, the forces acting on the cutter can be summarized in the Fig. 13 shown below.

Table 6: Crusher's motor specifications

Specifications	**Value**
Motor power (kw)	2.2
Motor speed (rpm)	195

Source: Shini Plastic Technologies Inc, 2010

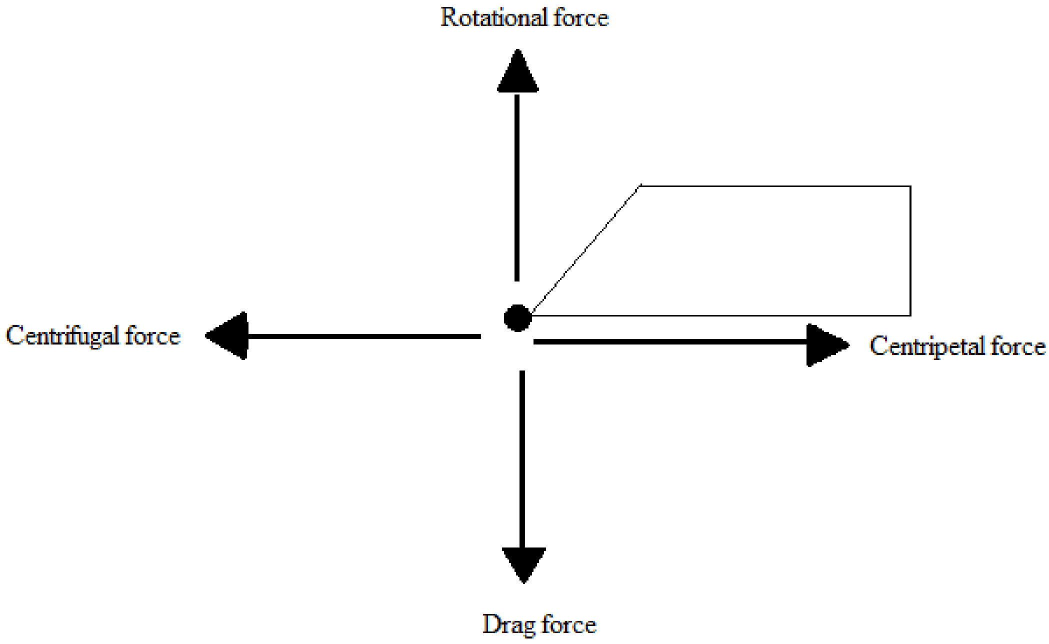

Fig. 16: Cutter's Free-body-diagram

Power

Motor power = 1.5kW, speed = 195 rpm

For proceeding calculating, motor power in Horsepower (HP) required:

Motor power = $2.2\ kW \times \frac{1\ HP}{0.746\ \ kW}$ = 2.95 HP

Torque

Formula: $T = \frac{5252\ \times HP}{rpm}$

where 5252 = constant
HP = horsepower
rpm = motor speed

$$T = \frac{5252\ \times 2.95}{195}$$

T = 79.45 lb-ft

Change to SI unit: 1 ft = 0.305 m

1 lb = 4.45 N

$$T = 79.45\ lb.ft\ \times \frac{0.305\ m}{1\ ft} \times \frac{4.45\ N}{1\ lb}$$

T = 107.83 N.m

<u>Force</u>

Formula: $T = F \times r$ where F = Force

r = distance from center of rotation

Torque = 107.83 N.m

Distance from center to tip of cutter (from the design) = 0.053 m

$$107.83 = F \times 0.053$$

∴ F = 107.83/0.053 = **2,034.58 N or 2.035 kN**

4.6 Materials Selection

Apart from the original material used to construct the crusher mechanism, another three candidates are added in the materials selection analysis in order to determine the suitable materials for the new design. In order to select the best materials to be used in constructing the mechanism, a total of four mechanical properties which are critical for crushing mechanism are selected, discussed as follow:

Modulus of Rigidity

Modulus of rigidity or also known as Shear Modulus is the coefficient of elasticity for a shearing force. It is defined as “the ratio of shear to the displacement per unit sample length (shear strain)” (Engineering ToolBox, 2010). This property is the most important in materials selection process as the cutter uses shearing force to cut the palm fiber and shell. Thus, the candidates selected are having the Modulus of Rigidity around the original material used, Dc53.

Modulus of Elasticity

Also known as Young’s modulus, this property is a measure of the stiffness of an isotropic elastic material (Wikipedia, 2010). In other words, Modulus of elasticity is the ratio of stress to strain of material, how much stress it can sustain given a specified strain. This property is essential in selecting the suitable materials as sufficient elasticity is required to avoid plastic deformation.

Coefficient of thermal expansion (CTE) and density

CTE determines the rate of expansion of material given a specific temperature and it is included in the selection process to ensure the material expansions are close to the original expansion. Density is also included in the material selection process because the mass of the selected materials must be close to the original, Dc53', to prevent excessive momentum produced, which can contribute extra stresses on the rod and locker.

Table 7 below shows the weighted-table of properties for the materials selection process.

Table 7: Weighted-table

Properties	Weight	DC53	w	Stainless steel	x	Cast Iron	y	Mild Steel	z
G (Gpa)	5	58.5	292.5	77.2	386	41	205	79.3	396.5
Y (Gpa)	3	150	450	200	600	92.3	276.9	210	630
CTE (µm/m-C)	1	12.3	12.3	17.3	17.3	10.5	10.5	12.6	12.6
Density (g/cm³)	1	7.76	7.76	8.03	8.03	7.15	7.15	7.88	7.88
Total weighted		DC53 =	762.56	SS =	1011.33	CI =	499.55	MS =	1046.98
Remarks		Medium ductility		Low ductilility		Brittle		High ductility	

G = Modulus of Rigidity (elasticity for sharing force)
Y = Modulus of elasticity (tendency to be deformed elastically)
CTE = coefficient of thermal expansion

Source: Linquist Steels, Inc (2004), ASM International (2010)

Based on the total scores of each candidate, the materials are sorted to contruct different parts of the crushing mechanism from most critical to least critical: Rod and locker > Roller > Cutter, shown in the Fig. 14 below.

Total weighted	DC53 = 762.56	SS = 1011.33	CI = 499.55	MS = 1046.98
Remarks	Medium ductility	Low ductilility	Brittle	High ductility

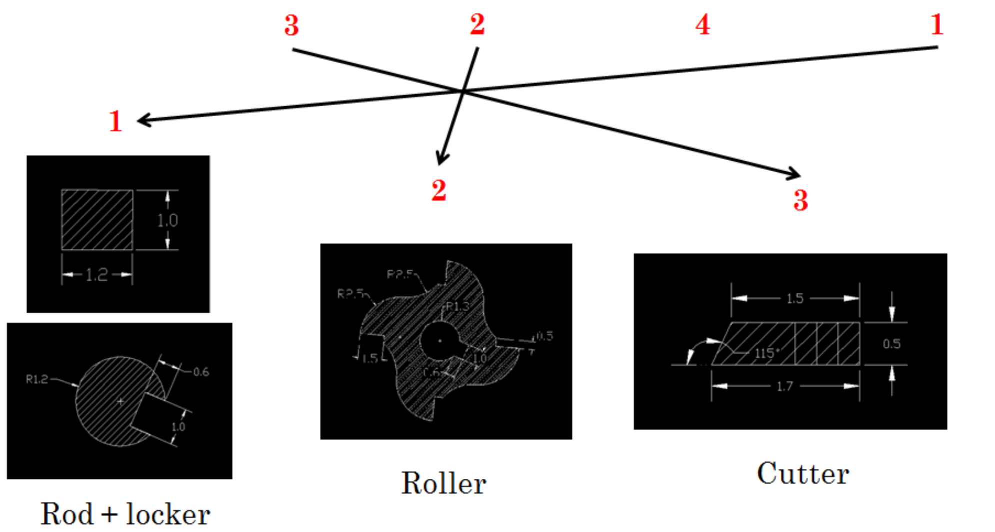

Fig. 17: Materials match-up

Mild steel is selected to construct most critical part of the mechanism, the rod and locker. Both rod and locker experiencing considerable amount of stress as this part required to rotate the roller as well as cutter, and high ductility is required so that the rod and locker will not fracture as the load increases. Stainless steel which has second highest score is selected to contruct the roller as this part is required to deliver the rotational force from rod to the cutter, thus higher tension compared to cutter. Last part is the cutter with the original material maintained, Dc53, which has medium ductility to avoid fracture.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

From all the research, study, engineering applications and analyses which have been carried out on several market designs, with lab-scaled and United States Patent as the base references, the new design of crushing mechanism has been produced. The combination of the two base designs yield better crusher mechanism as the designs of US patent are adapted into the dimensions and working parameters of the lab-scaled crusher. As mentioned in Chapter 1, there are three objectives of this project, namely:

1. To design a crushing mechanism of a biomass briquetting machine.
2. To generate engineering detailed drawings.
3. To perform materials selection analyses.

All of these objectives have been achieved throughout the one year of project period. First objective achieved where few crushing mechanism were generated and the combination of US patent and lab-scaled crusher are selected. The engineering drawing for the new design has been produced using AutoCAD 2007, thus completing the second objective. The third objective requires material selection analyses and this process has been carried out in the last part of the project.

For future work expansion, it is recommended to increase the number of rotating cutter to cater for greater capacity. As the number of cutter increases, the crushing process will require less time for the same capacity because more cutting process can be carried out a time. Apart from that, the number of roller can also be increased, thus increasing the size of cutting chamber and leads to much greater capacity of production.

As the materials selected for the crushing mechanism in the materials selection analyses have higher mechanical properties than the original, thus the power and speed of the motor can be increased if the production time needs to be decreased. So, it is recommended to vary the speed of the motor for future work expansion to determine the suitable speed and power for the selected materials.

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