OPTIMIZATION OF CYCLONE EFFICIENCY FOR SEPARATION OF FIBRE AND SHELL FROM PALM KERNEL

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OPTIMIZATION OF CYCLONE EFFICIENCY FOR SEPARATION OF FIBRE AND SHELL FROM PALM KERNEL

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A dissertation submitted in partial fulfillment of the Requirements for the award of the degree of Bachelor of Engineering (Chemical Engineering)

Faculty of Chemical and Natural Resources Engineering
Universiti Malaysia Pahang

APRIL 2010

I declare that this dissertation entitled "*Optimization of Cyclone Efficiency for Separation of Fibre and Shell from Palm Kernel*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Name : Khairul Azlan bin Ismail

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To my family members,
my friends – reality or virtual,
my fellow colleagues,
and all faculty members

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ABSTRACT

In separation of shell and fibre from kernel seed, palm oil mill normally employed cyclone system. A cyclone collection consists of cylindrical shell, conical base, dust hopper, and an inlet where the dust laden enters tangentially. Under the influence of the centrifugal force generated by the spinning gas, the solid particles are thrown to the wall of the cyclone as the gas spirals upward at the inside of the cone. The particles slide down to the wall of the cone and into the hopper. The operating or separating efficiency of a cyclone depends on the magnitude of the centrifugal force exerted on the particles. The greater the centrifugal force, the greater the separating efficiency. The magnitude of the centrifugal force depends on particle mass, gas velocity within the cyclone and cyclone diameter. For a practical test to increase the cyclone efficiency for kernel recovery, gas velocity can be manipulated to achieve highest separation efficiency instead of modifying the cyclone design. In experimental, the total load entering the system and various inlet velocity of the cyclone is measured. The kernel and shell production will be measured 1 hour after change is made. Data obtained was analyzed to determine the inlet air velocity for the maximum separation efficiency indicates by the highest peak of kernel production in graph. The result compared 2 loads entering the system and the different load give different best air velocity. Increase the load will increase the best inlet air flow. Higher air velocity will reduce the separation efficiency.

ABSTRAK

Dalam pemisahan tempurung dan serat dari biji kernel, kilang kelapa sawit biasanya menggunakan sistem siklon. Siklon terdiri daripada silinder, dasar kon, pengumpul debu, dan salur masuk di mana debu bermuatan masuk secara tangen. Di bawah pengaruh daya putaran yang dihasilkan oleh putaran gas, zarah pepejal yang dilemparkan ke dinding siklon bergerak ke atas secara memutar di bahagian dalam kon. Zarah bergerak ke bawah dinding kon dan masuk ke pengumpul. Kecekapan operasi ataupun pemisahan siklon bergantung pada daya pusingan yang dikenakan pada zarah. Semakin besar daya pusingan, semakin besar kecekapan pemisahan. Besarnya daya putaran bergantung pada jisim zarah, kelajuan gas didalam siklon dan diameter siklon. Untuk menguji secara praktikal bagi meningkatkan kecekapan siklon untuk pemulihan kernel, kelajuan gas boleh dimanipulasi untuk mencapai kecekapan yang tinggi, selain memodifikasi rekabentuk siklon. Untuk ujian, jumlah beban yang masuk ke dalam sistem dan halaju angin memasuki siklon diukur. Pengeluaran kernel dan tempurung akan diukur selepas 1 jam ubahan dilakukan. Data diperolehi dianalisis untuk menentukan kelajuan angin masuk bagi menentukan kecekapan maksimum pemisahan yang ditunjukkan oleh puncak tertinggi pengeluaran kernel dalam graf. Keputusan ujian membandingkan 2 beban yang memasuki sistem dan beban yang berbeza memberikan kelajuan udara terbaik yang berbeza. Meningkatkan beban akan meningkatkan kelajuan angin yang terbaik. Kelajuan udara yang lebih tinggi akan mengurangkan kecekapan pemisahan.

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LIST OF ABBREVIATIONS

CPO	- Crude palm oil
CPKO	- Crude palm kernel oil
POM	- Palm oil mill

LIST OF SYMBOLS

%	- Percent
^{o}C	- Degree Celcius
m/s	- Meter per second
kg/s	- Kilogram per second
MT	- Metric tonne
F_c	- Centrifugal force
M_p	- Particulate mass
v^2	- Particle velocity
R	- Radius

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia is one of the world leaders in the production and export of crude palm oil. In 2006, crude palm oil produced reached 15.9 million tones. The oil palm industry in Malaysia has contributed immensely toward the country's economic well being. During the economic crisis in 1997/1998, the industry has helped to cushion the impact of economic downturn through its export oriented activities, which provide the much needed foreign exchange for the country.

Oil palm industry is a self-sufficient industry. The concept of recycling of the palm oil mill by product is not new but merely resurfaces in the light of recent economic and environmental concern. By-product of palm oil mill is kernel and fibre. The fibre will can be used as the burning fuel for boiler to generate electricity and the kernel can be sold.

Over the year, the oil palm industry have been very responsible and all the by product have been utilize. Since the1980s, the judicious utilization of the various by-products through nutrient recycling in the field has reduced the environmental impact paving the way toward zero waste policy. Generally, some of the by product mainly shell and mesocarp fibre are used as fuel in boiler to generate steam to run the turbine to generate electricity.

Research and development work in many disciplines - biochemistry, chemical and mechanical engineering - and the establishment of plantations, which provided the opportunity for large-scale fully mechanized processing, resulted in the evolution of a sequence of processing steps designed to extract, from a harvested oil palm bunch, a high yield of a product of acceptable quality for the international edible oil trade. The oil winning process, in summary, involves the reception of fresh fruit bunches from the plantations, sterilizing and threshing of the bunches to free the palm fruit, mashing the fruit and pressing out the crude palm oil. The crude oil is further treated to purify and dry it for storage and export.

Efforts to mechanize and improve traditional manual procedures have been undertaken by research bodies, development agencies, and private sector engineering companies, but these activities have been piecemeal and uncoordinated. They have generally concentrated on removing the tedium and drudgery from the mashing or pounding stage (digestion), and improving the efficiency of oil extraction. Small mechanical, motorized digesters (mainly scaled-down but unheated versions of the large-scale units described above), have been developed in most oil palm cultivating African countries.

Palm oil processors of all sizes go through these unit operational stages. They differ in the level of mechanization of each unit operation and the interconnecting materials transfer mechanisms that make the system batch or continuous. The scale of operations differs at the level of process and product quality control that may be achieved by the method of mechanization adopted.

1.2 Background of Study

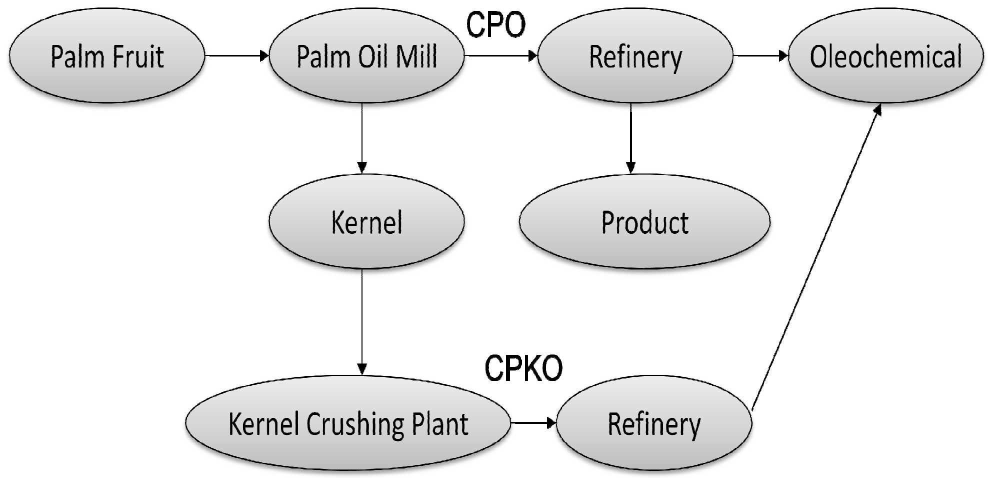

Figure 1.1: Overall Palm Oil Industry

Based on figure 1.1, in palm oil industry, palm oil mill will only extract the crude palm oil (CPO) and kernel from the palm fruit. The CPO will be sent to refining industry and will be converted into another product. Kernel recovered from palm fruit will be sent to kernel crushing plant to extract the crude palm kernel oil (CPKO). The CPKO will be sent to refinery and oleo chemical. The kernel may also being converted into another product such as animal feedstock and will not be sent into kernel crushing plant. All by product will be recycled or sell. The fibre will be used as the burning fuel inside the boiler to generate electricity. In palm oil mill several processes will be done to extract the crude palm oil.

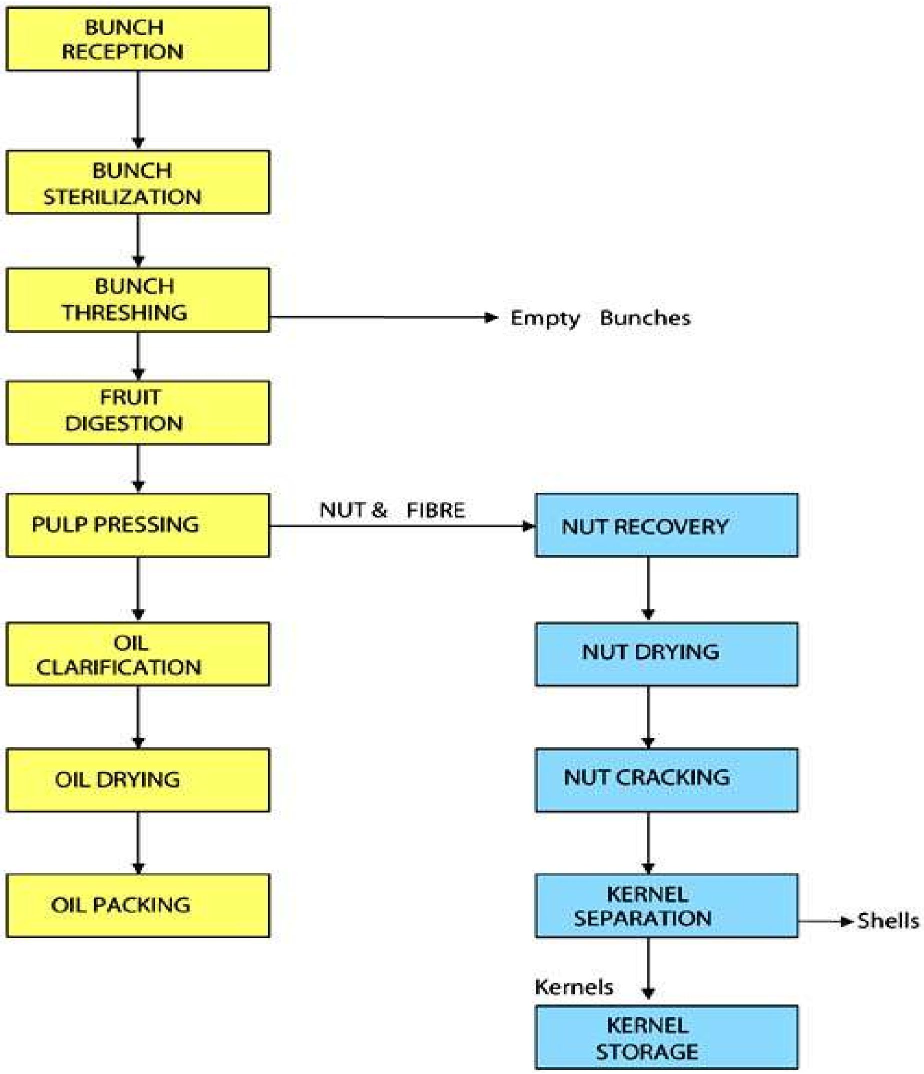

Figure 1.2: Palm oil mill process

The palm oil processing units start with harvesting as shown in figure 1.2. Harvesting involves the cutting of the bunch from the tree and allowing it to fall to the ground by gravity. Fresh fruit arrives from the field as bunches or loose fruit. Manual threshing is achieved by using a rotating drum or fixed drum equipped with rotary beater bars detach the fruit from the bunch, leaving the spikelets on the stem. The fruit is then sterilized. Sterilization or cooking means the use of high-temperature wet-heat treatment of loose fruit causes the moisture in the nuts to expand and leads to the detachment of the kernel from the shell wall, thus loosening the kernels within their shells.

Digestion takes part after the sterilization process. Digestion is the process of releasing the palm oil in the fruit through the rupture or breaking down of the oil-bearing cells. There are two distinct methods of extracting oil from the digested material. One system uses mechanical presses and is called the ‘dry’ method. The other called the ‘wet’ method uses hot water to leach out the oil. The crude palm oil from the presses contains a mixture of palm oil, water and fibrous materials in varying proportions. It is pump to a continuous horizontal or vertical clarification tank for oil separation.

The press discharge from the screw press consists of moist and oily fibre nuts including broken ones and kernels. This mixture is conveyed to a Depericarper for nut and fibre separation. The fibre and nuts are separated by a strong air current induced by a suction fan. The air velocity has to be accurately determined for efficient nut and fibre separation (Abdullah Ariffin and Mohd Nasir Hasan Basri, 1994).

Nut and kernel treatment consist of four distinct operations which are nut conditioning, nut cracking, kernel and shell separation and kernel drying. For ideal nut cracking, it is necessary to heat the nut to dry them sufficiently to loosen the kernel ands and then cool the nut to harden the shell before cracking and this process is referred as nut conditioning. Then it will be cracked using machine which are almost invariably of the centrifugal type in which the nut are given velocity by being fed through the rotor and are caused to crack by being flung against the stator ring (Abdullah Ariffin and Mohd Nasir Hasan Basri, 1994).

There are some machine used for kernel and shell separation such as winnowing, Wilder Dry separator, clay bath separator and hydrocyclone separator. The kernel is the dried. The moisture content of fresh kernels is about 20% and if bagged in this condition would soon become mouldy and in addition there would be a rapid increase in the FFA of palm kernel oil (Abdullah Ariffin and Mohd Nasir Hasan Basri, 1994).

1.3 Problem Statement

In separation of shell and fibre from kernel, palm oil mill normally employed cyclone system. In the process, nut will enter depericarper to be separated from fibre and then will enter either winnowing, wilder dry or hydrocyclone to separate its shell. The similarity of all process used is it using cyclone system separator. The inefficiency of cyclone is due to uneven of the inlet air flow rate. The amount of dirt associated to kernel has contributed to the cyclone inefficiency; hence the separation technique is not totally workable. Thus, inefficiency also causes less fibre to be obtained for fuel purposes.

1.4 Objective of Research Project

The objective of the research project is to improve the efficiency of cyclone separation of fibre and shell from kernel by manipulating the velocity of inlet air flow rate, increase kernel production and increase the profit gain by the company.

1.5 Scope of Research Project

i. To study the effect of different velocity of air flow enter the cyclone.
ii. To study the separation process of fibre and shell from kernel.
iii. To study the oil and kernel losses in cyclone fibre.
iv. To study the effect of oil and kernel losses due to inefficient cyclone
v. To study the dirt removal in kernel recovery
vi. To study the effect of load amount on cyclone efficiency

CHAPTER 2

LITERATURE REVIEW

2.1 Oil palm fruit

The Palm tree fruit is various in form, size and character; sometimes, as in the common date it is a berry with a fleshy rind enclosing a hard stony kernel, the true seed; the fruit of Areca is similar; sometimes it is a kind of drupe as in Acrccomia, or the coconut, Cocos nucif era, where the fibrous central portion investing the hard shell corresponds to the fleshy portion of a plum or cherry, while the shell or nut corresponds to the stone of stone-fruits, the seed being the kernel (Kalyana Sundram, 2009). In Borassus the three seeds are each enclosed in a separate chamber formed by the stony endocarp. Sometimes, as in the species of Metroxylon, Raphia, Daemonorops, &c,, the fruit is covered with hard, pointed, reflexed shining scales, which give it a very remarkable appearance (Sundram K et al, 2003).

The oil palms (Elaeis) comprise two species of the Arecaceae, or palm families which are used in commercial agriculture in the production of palm oil (Kalyana Sundram, 2009). The African Oil Palm Elaeis guineensis is native to west Africa, occurring between Angola and Gambia, while the American Oil Palm Elaeis oleifera is native to tropical Central America and South America. The generic name is derived from the Greek for oil, elaion, while the species name refers to its country of origin. (Kalyana Sundram, 2009).

Mature trees are single-stemmed, and grow to 20 m tall. The leaves are pinnate, and reach between 3-5 m long. A young tree produces about 30 leaves a year. Established trees over 10 years produce about 20 leaves a year. The flowers are produced in dense clusters; each individual flower is small, with three sepals and three petals (Sundram K et al, 2003).

The palm fruit takes five to six months to mature from pollination to maturity. Each fruit is made up of oily, fleshy outer layer (the pericarp), with a single seed (kernel), also rich in oil. When ripe, each bunch of fruit weighs 40-50 kilogrammes. The palm fruit is reddish, about the size of a large plum and grows in large bunches. Each fruit contains a single seed (the palm kernel) surrounded by a soft oily pulp.

Oil is extracted from both the pulp of the fruit (palm oil, edible oil) and the kernel (palm kernel oil, used mainly for soap manufacture). For every 100 kilograms of fruit bunches, typically 22 kilograms of palm oil and 1.6 kilograms of palm kernel oil can be extracted (Sundram K et al, 2003).

The high oil yield of oil palm trees (as high as 7,250 liters per hectare per year) has made it a common cooking ingredient in southeast Asia and the tropical belt of Africa. Its increasing use in the commercial food industry in other parts of the world is buoyed by its cheaper pricing, the high oxidative stability of the refined product and high levels of natural antioxidants (Sundram K et al, 2003).

Since palm oil contains more saturated fats than canola oil, corn oil, linseed oil, soybean oil, safflower oil, and sunflower oil, it can withstand extreme deep fry heat and is resistant to oxidation (De Marco et al, 2007)

2.1.1 Oil palm kernel

Palm kernel cakes are the leftovers after kernel oil is pressed out from the nut in the palm fruit. Palm kernel cake is commonly used as animal feed for dairy cattle because of its high protein content. If not, it is usually treated as biomass to fuel up boilers to generate electricity for use at palm oil mills and surrounding villages. There are two types of palm kernel cake, depending on the process to get it either through mechanical or solvent process. In Malaysia, mechanical extraction by screw press is the most widely used. The solvent extraction process is generally not used because it is more expensive (Hishamudin, 2001).

Although palm kernel cake supplies both protein and energy, it is looked upon more as a source of protein. Palm kernel cake is a reasonably good economic feed for cattle, both for fattening and supplementary feeding. It has effectively reduced the cost of milk production in Malaysia because it is a substitute of costly imported feedstuffs like soybean meal and ground maize (FY Chin, 1992)

Palm kernel cake, by itself, is a medium grade protein feed and with its high fibre content is often thought of being more suitable for feeding of ruminants (Carvalho et al, 2006). Palm kernel cake is ranked a little higher than copra cake and cocoa pod husk but lower than fish meal and groundnut cake, especially in its protein value (Wong Hee Kum et al, 1997).

Besides oil and protein, palm kernel cake also has high fibre content of 16 per cent and high phosphorus to calcium ratio. Also present are essential elements like magnesium, iron and zinc (Tang Thin Sue, 2001). The typical feed ration formulated for the feeding of dairy cattle comprises 50 per cent palm kernel cake, molasses (5 per cent), grass/hay (42 per cent), limestone (1.5 per cent), mineral premix (1 per cent) and salt (0.5 per cent) and trace element of vitamin premix (M Wan Zahari et al, 2004).

2.1.2 Oil palm fibre

Oil palm trunk fiber is very light and can absorb a lot of water without congealing. It can withstand extremes temperature and moisture conditions during food processing. This natural fiber has a wide range of applications in foods where fiber usually is added, such as yogurts, breads, pastries and other products using wheat (Ridzuan Ramli, 2002).

A cereal made using oil palm trunk fiber has been introduced in Malaysia through Sukhe International, the Selangor Daru Ehsan-based company which extracts oil palm trunk fiber using a patented process. The success of oil palm trunk fiber in the functional foods market mean Malaysia can generate revenue out of a waste product that has, until now, proved problematic (Lim Kim Chiew and Zaharah A Rahman, 2002)

Malaysia produces 50 percent of the world's palm oil and has 3 million hectares of the trees under cultivation. Every year, 9 million trees become nascent and must be cut down, with saplings planted in their stead. Oil palm fibre is equivalent to coconut fiber at a competitive price. Oil palm fiber is non-hazardous biodegradable material extracted from oil palm's empty fruit bunch (EFB) through decortation process. The fibers are clean, non-carcinogenic, free from pesticides and soft parenchyma cells (Lim Kim Chiew and Zaharah A Rahman, 2002)

Palm fibres are versatile and stable and can be processed into various dimensional grades to suit specific applications such as mattress cushion production, erosion control, soil stabilization/compaction, landscaping and horticulture, ceramic and brick manufacturing, thermoplastic filler, flat board manufacturing, paper production, acoustics control, livestock care, compost, fertilizer, animal feed, etc. (Lim Kim Chiew and Zaharah A Rahman, 2002).

In palm oil mill, the separated fibre from the fruit will be sent to boiler to generate electricity. This process already been used by all palm oil mill in order to save energy consumption. The electrical energy generated is enough to be used by the mill. Burned fibre will remove from the boiler and may be converted into fertilizer.

2.1.2 Oil palm Shell

Shell also known as endocarp is recovered from the nut after the nut cracking using the cyclone. Shell will be used as the burning fuel along with the fibre. The fibre is fully required in the mill for this purpose. However, only about 30% of shell is utilized for this purpose (Abd Halim, 1985). Thus, the mills have generally excess shell which is not used and which needs to be disposed of separately. Normally, shell is about 10-11% from the fruit and it will not produce any oil.

Palm kernel shells have a very low ash and sulphur contents. Ash content typical about 3% weight and sulphur content typical about 0,09% weight. Palm kernel shells can be considered like a natural pellet and an high grade solid renewable fuel for burning, as received, both in co firing with steam coal or burned at biomass power plants, usually blended with other grades of biomass, like wood chips (Abd Halim, 1985).

2.2 Equipment Used for Kernel Separation

2.2.1 Depericarper

The Depericarper consist of a rotating drum through which a current of air is passed. The cake firm the matte breaking conveyor is fed in at one end of the drum via a short closed length of conveyor, which acts as an air seal, and passes along the drum. Lifting arms are fitted so that the nut and fibre are continually lifted up and then fall down back to the drum (K.G Berger, 1989). Annular baffles slow doe the movement of the nuts along the drum. A current of air passes through the drum in the direction of the motion of the nuts and fibre and thus s induced by a powerful fan mounted in the ducting above the separator at the outlet end. The air was originally heated before it enters the drum, is sucked through the fan and then blown through ducting to the cyclone. The nuts leaving the separator drum pass through smaller rotating drum which is known as the polishing drum (K.G Berger, 1989).

Nuts from the depericarper drum will go to the polishing drum by elevator to remove fibers from nuts. After the polishing drum, the de-stoner fan will sucks fibers from nuts to the fiber cyclone, and nuts will go into the nut silos, then into nut cracker (ripple mill) to crack the nuts, to get cracked mixtures. These cracked mixtures will go through 2 winnowing systems (LTDS) for separation.

2.2.2 Low Tension Dust Separator

The low tension dust separator or the LTDS as it is popularly known can contribute significantly toward the losses kernel, simply because of the separating velocity of the separating column is set erratically and no one has the equipment to measure it. By careful adjustment, the optimum velocity suitable for the cracking mixture could be selected by adjusting the throat area of the separating column (Palm oil Engineering Bulletin, 2009). Shells and kernels or cracked mixture which are not 100% separated at the LTDS, conveyed to clay bath for further separation by using vibrating screen (Kim Loong, 2007)

2.2.3 Hydrocyclone

In recent years, alongside the traditional use of hydrocyclones in mineral processing, new applications, particularly in the field of environmental engineering, have opened up for these separators (Neesse and Donhauser). A hydrocyclone is a device to classify, separate or sort particles in a liquid suspension based on the densities of the particles. A hydrocyclone may be used to separate solids from liquids or to separate liquids of different density. A hydrocyclone will normally have a cylindrical section at the top where liquid is being fed tangentially, and a conical base. The angle, and hence length of the conical section, plays a role in determining operating characteristics (K.G Berger, 1989).

The action of the hydrocyclone is somewhat similar o that an air cyclone in that by imparting a circular motion to the fluid means of the tangential entry heavy particles are thrown by centrifugal force to the wall of the cylinder and after tracing a helical path find their way out through the bottom of the cyclone while lighter particle after taking part in an initial downwards circular movement gradually move towards the centre of the cylinder and start moving upwards leaving the cyclone via the over flow tube (K.G Berger, 1989).

Internally, centrifugal force is countered by the resistance of the liquid, with the effect that larger or denser particles are transported to the wall for eventual exit at the reject side with a limited amount of liquid, whilst the finer, or less dense particles, remain in the liquid and exit at the overflow side through a tube extending slightly into the body of the cyclone at the center (Dyakowski et al, 1999)

Forward hydrocyclones remove particles that are denser than the surrounding fluid, while reverse hydrocyclones remove particles that are less dense than the surrounding fluid. In a reverse hydrocyclone the overflow is at the apex and the underflow at the base. There is also parallel-flow hydrocyclones where both accept and reject are removed at the apex. Parallel-flow hydrocyclones remove particles that are lighter than the surround fluid (Neesse and Donhauser).

2.2.4 Clay bath Separator

Clay bath separator is the only method of separating the kernel form its shell and fibre without using cyclone system. The specific gravity of the undried kernels is about 1.07 and that of shell about 1.17 and therefore in a clay and water mixture of specific gravity 1.12 kernels will float and shell will sink; this is the principle on which the clay bath works. Many models were developed from the manually operated to completely automatic versions. As suitable clays were not always readily available salt solutions and even dilute molasses were tried for the suspension. The clay bath is quite an efficient separator as long as the density of the suspension is maintained at the correct value. However when processing the cracked mixture form tenera nuts troubles can be experienced with a small long bearded nuts coming over with the kernel (K.G Berger, 1989).

Clay bath separators tend to be rather messy and with the introduction of the hydrocyclone separator and the clay bath soon dropped out of favour even though the hydrocyclone need more power and capital outlays. Because of the heavy maintenance cost and power demand associated with hydrocyclone there has been a recent trend to adopt a winnowing system follow by a clay bath for a cracked mixture separation (K.G Berger, 1989).

2.2.5 Cyclone

Cyclones are among the oldest types of industrial particulate control equipment and are still one of the most widely used of all industrial gas-cleaning devices (Bahrami et al, 2008). Cyclone separators are widely used in the field of gas–solid separation for both engineering and process operations (Zhao Bing-tao, 2006). Their relative simplicity in fabrication, low cost in operation and well adaptability to extremely harsh conditions make them, as important equipment, especially useful in applications involving milling technologies for coal-fuelled boilers in power plants (Zhao Bing-tao, 2006).

A cyclone collection consists of cylindrical shell, conical base, dust hopper, and an inlet where the dust laden enters tangentially (Howard et al, 1985). The gas flow is forced into a downward spiral simply because of the cyclone's shape and the tangential entry (Bahrami et al, 2008). Under the influence of the centrifugal force generated by the spinning gas, the solid particles are thrown to the wall of the cyclone as the gas spirals upward at the inside of the cone. The particles slide down to the wall of the cone and into the hopper. The main reasons for the widespread use of cyclones are that they are inexpensive to purchase, they have no moving parts, and they can be constructed to withstand harsh operating conditions (Bahrami et al, 2008).

The operating or separating efficiency if a cyclone depends on the magnitude of the centrifugal force exerted on the particles. The greater the centrifugal force, the greater the separating efficiency (Howard et al, 1985). Te magnitude of the centrifugal force depends on particle mass, gas velocity within the cyclone and cyclone diameter as shown in equation below:

$$F_c = M_p \text{ x } v_i^2/R$$

Where F_c = Centrifugal force, N

M_p = Particulate mass, kg

v_i^2 = Particle velocity, m/s

R = Radius of the cyclone, m

From the equation, it can be seen that the centrifugal force o the particle, and thus the collection efficiency of the cyclone separator, can be increase by decreasing R, the radius of the cyclone (Howard et al, 1985). Large diameter cyclones have good collection efficiency particles 40 to 50 μm in diameter. High efficiency cyclones with diameter of 23 cm or less have good efficiencies for particle from 15 to 20 μm. Multiple cyclones operating in parallel are necessary to treat large flow when small diameter of cyclone are used. The smaller radius of the cones not only increases the centrifugal force, but also reduces the distance the particles have to travel to reach the collections chamber. Small cyclones do have some disadvantages, such as problem with equalizing gas flow to each cone, abrasion of tubes due to high velocity and plugging of heavily loaded tube. Cyclones usually build to standard relative dimensions (Howard et al, 1985).

2.3 Cyclonic Separation

A full understanding of how the cyclone separator works and how individual particles behave within it is not yet available (Hemdan Hanafy Shalaby, 2007). Cyclones are one of the most common inertial devices and used for a variety of applications, such as; ambient and source sampling and particulate matter control, because of their simplicity of design, low maintenance costs, and adaptability to a wide range of operating conditions (K.S.Lim *et al*, 2002).

The cyclone separator in its many is an old device which has been the subject of many investigations. Evaluations of cyclone performance have long been studied to better understand and improve cyclone design theory (Bahrami A. et al, 2008). Basically the cyclone uses the flow through a nozzle or a set of blades to cause the fluid within the cyclone chamber to rotate. This rotation develops a centrifugal force field which tends to cause particles more dense than the fluid to move radially outward from the center of rotation. Separation is affected by forcing the fluid to move inward before it escapes from the cyclone chamber. The centrifugal separation force on the particle is opposed by the drag due to the relative motion of the particle through the fluid. The dense particle are either bled off with the small amount of fluid or conveyed to a low velocity region where they settle out by gravity. The rotating flow in the cyclone automatically and conveniently provides the conveying flow (Joseph Le Conte Smith Jr, 1959)

Cyclonic separation is a method of removing particulates from an air, gas or water stream, without the use of filters, through vortex separation. Rotational effects and gravity are used to separate mixtures of solids and fluids. A high speed rotating air flow is established within a cylindrical or conical container called a cyclone. Air flows in a spiral pattern, beginning at the top (wide end) of the cyclone and ending at the bottom (narrow) end before exiting the cyclone in a straight stream through the center of the cyclone and out the top. Larger (denser) particles in the rotating stream have too much inertia to follow the tight curve of the stream and strike the outside wall, falling then to the bottom of the cyclone where they can be removed. In a conical system, as the rotating flow moves towards the narrow end of the cyclone the rotational radius of the stream is reduced, separating smaller and smaller particles. The cyclone geometry, together with flow rate, defines the cut point of the cyclone. This is the size of particle that will be removed from the stream with a 50% efficiency. Particles larger than the cut point will be removed with a greater efficiency and smaller particles with a lower efficiency.

A particle in the cyclonic flow will move towards either the wall of the cyclone or the central axis of the cyclone until the drag, boyant and centrifugal forces are balanced. Assuming that the system has reached steady state, the particles will assume a characteristic radius dependent upon the force balance. Heavier, denser particles will assume a solid flow at some larger radius than light particles. These technologies demand high efficiency of cyclones to provide satisfactory and economical performance, ensure regulatory compliance and protect expensive downstream components (Zhao Bing-tao, 2006).

2.4 Collection Efficiency

Two important parameters in cyclone separator operation, collection efficiency and pressure drop, are strongly influenced by the inlet particle concentration (Zhongli Ji *et al*, 2008). Cyclones, however, have low collection efficiency for small particles due to their reliance on inertial forces to separate particles from gas streams. The need to improve their collection efficiency has lead to a renewed interest in their design.

Cyclone collection efficiency is defined as the fraction of particles of a given size that is retained by the cyclone (Fabio Luis Fassani and Leonardo Goldstein Jr, 1999). It also can be defined as the ratio between the mass of solids collected by the cyclone in a time interval and the mass flow rate of incoming solids (Fabio Luis Fassani and Leonardo Goldstein Jr, 1999).The theories that have been developed to predict efficiency differ greatly in complexity. There is a general agreement that operating parameters of the system should be used to predict performance and most theories account for the influence of particle diameter and density and gas velocity and viscosity (John Dirgo and David Leith, 1985).

Collection efficiency, the ratio of particles collected to particles injected, is one of the most important parameters used in evaluating the performance of a cyclone. If this ratio is applied to only a single particle diameter, it becomes the grade or fractional efficiency. If this ratio is applied to only a single particle diameter, it becomes the grade or fractional efficiency. If the particle volume fraction or mass loading is low in a cyclone, particle transport is usually simulated using the Lagrange approach in CFD analysis (Liming Shi and David J. Bayless, 2006).

The particle collection efficiency of a cyclone separator depends on its geometric configuration, gas and particles physical properties, and on the operational conditions (Fabio Luis Fassani and Leonardo Goldstein Jr, 1999). Patterson and Munz (1996) studied the effects of concentration and flow temperature on the collection efficiency of a 0.102 m diameter cyclone, operated with air temperatures between 300 and 2000 K, inlet velocities from 3 to 42 m/s, and solid loadings up to 0.192 kg of solids/kg of gas. The increase of solid loading produced higher collection efficiencies, a trend that was more noticeable for higher gas temperatures. Hoffmann et al observed that the effect of solid loading was more pronounced for the lower velocities they used. With loadings from 4.0×10^{-3} to 106.0×10^{-3} kg of solids/kg of gas, Hoffmann et al noted an increase of the collection efficiency.

It is generally difficult to change the cut size in a conventional cyclone separator. To solve this problem, researchers found that it is possible to change the cut size by the use of a moving circular guide plate at the cyclone inlet or by the use of an additional secondary flow injection method in the upper cylindrical part of cyclone.

The efficiency of separation of cyclone separators depends on the centrifugal field formed inside the cyclone separator. It is commonly known that the higher the angular velocity of the gaseous medium flow, the more intensive is the centrifugal field, and that the intensity of the centrifugal field is directly proportional to the second power of the angular velocity of the medium flow. This is why small-diameter cyclone separators are more efficient separators than cyclone separators of larger diameter. It also comes from this that, in practical solutions, multi-cyclones are adopted more and more frequently even though their investment cost and power consumption are higher. In spite of this, cyclone separators are not capable of meeting the requirements of good efficiency of separation (Viljo Jarvenpaa, 1999)

2.5 The separation of fibre from nut

The separation of the cake into its components gives rise to some difficulties in case of processing of the selected fruit. As a result of the pressure exerted during the extraction process except in the wet process, nut and fibre from the compact mass which it is essential to break up prior to separation (Mangana Report, 1955).

The breaking up has been attempted in a mixer, in a cake breaker conveyor and in an apparatus original conception working on the principle of the carding machine. Only the cake conveyor gives complete satisfaction (Mangana Report, 1955). The effect of the speed of the rotation of the blades and of the diameter of the through was studied. It appears from the experimental work that the breaking up only occur beyond certain speed of rotation, for lower speed, the cake is simply churned up without being teased (FY Chin, 1992)

Breaking up is easy in the case of continuous press cake which is well extracted, has low cellular debris content and short fibrous strands. The cake derived from extraction in a centrifuge has a higher oil and cellular debris content. For this reason, it has a tendency to mass up into a lumps consisting of cellular debris intimately mixed with long fibrous strands. This lump is very rare in the cake as it comes out of the extraction equipment. They have the tendency to form as result of handling, particularly in drum where the material tumbles over whilst being subjected to rotation(Mangana Report, 1955).

2.6 Effect of load amount

The effect of loading is there could be a small increase of collection efficiency with increasing loading, explained by the coarser particles carrying the finer ones to the cyclone circumference, where they were collected (A.J. ter Linden, 1949). Correlated data from several sources and reported an increase in collection efficiency with solid loading in the range of $1.868x10^3$ to $186.8x10^3$ kg of solids/kg of gas (Stern et al, 1955). Several particles and solid loadings up to 0.082 kg of solids/kg of gas, with 15 and 20 m/s inlet velocities tested, observing the same trend (Mori et al, 1968). For higher solid loadings, between $1.868x10^3$ and 1.868 kg of solids/kg of gas also shows increasing collection efficiency, notably for the smaller particles (Zenz, 1975).

The concentration and flow temperature also affect the collection efficiency of a 0.102 m diameter cyclone, operated with air temperatures between 300 and 2000 K, inlet velocities from 3 to 42 m/s, and solid loadings up to 0.192 kg of solids/kg of gas. The increase of solid loading produced higher collection efficiencies, a trend that was more noticeable for higher gas temperatures (Patterson and Munz, 1989). The effect of solid loading was more pronounced for the lower velocities they used. With loadings from $4.0x10^3$ to $106.0x10^3$ kg of solids/kg of gas, there are slightly increase in the collection efficiency (Hoffmann et al, 1991).

No effect was observed for loadings varying from $0.3163x10^3$ to $41.0x10^3$ kg of solids/kg of gas (Fabio Luis Fassani and Leonardo Goldstein Jr, 1999).). As concerns a cyclone operating in a circulating fluidized bed, a test carried out three in a 0.406 m diameter separator, with solid loadings from 1.4 to 5.6 kg of solids/kg of gas, and a gas entrance velocity of 3.6 m/s. The results indicated a reduction in collection efficiency with increasing solid loading, markedly for smaller particles (Tuzla and Chen, 1992). No variation in collection efficiency was found up to 0.816 kg of solids/kg of gas. In the range from 1.633 to 6.531 kg of solids/kg of gas a slight efficiency increase was observed in tests carried out with 484 and 807 m average diameter particles, but not in the 356 m particle tests (Fabio Luis Fassani and Leonardo Goldstein Jr, 1999)

CHAPTER 3

METHODOLOGY

3.1 Introduction

The experiment will be tested on the effect of vary inlet air velocity of the separation efficiency of the cyclone. The design of the cyclone cannot be adjusted. Changing the cyclone will be costly. The particle load into the cyclone is always kernel with vary size frequency. This test is conducted to prove that the vary air inlet velocity give effect on the production of kernel and shell. Below are the steps required for the test.

3.2 Procedure

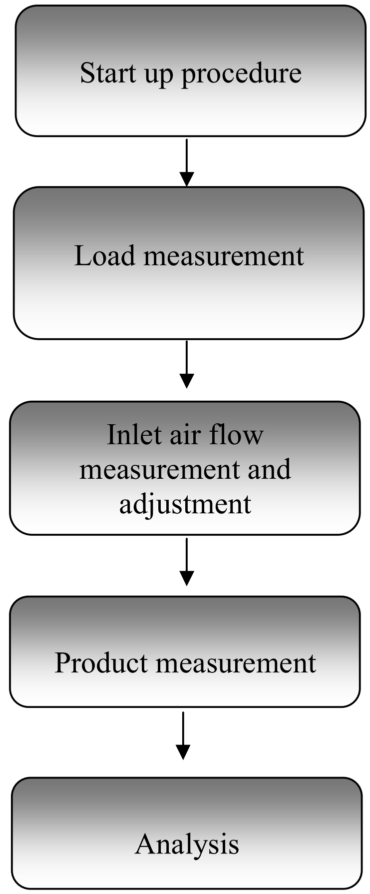

Figure 3.1: Experimental methodology

3.2.1 Start up procedure

This step will be done by the machine operator at the Dominion Square Sdn. Bhd. The cyclone needs to be operated before the test can be conducted. All the equipment checked by the operator to make sure it can work properly. The foremen will monitor the test.

3.2.2 Load measurement

The load will enter the cyclone after the nut cracker. The mass of load entering the system are measured per unit time. At first, the time period proposed is hour. It means the total load entering the cyclone for 1 hour will be measured. The rejected and suggest that the load will be taken within 5 second due to too much load will be produce in 1 hour and the process will be disturbed. The load is taken 3 times and the average value is calculated. The load enter are measured regularly. Its data is taken before the inlet air flow is changed, after changed and 1 hour after the change which is before the product is measure.

3.2.3 Inlet air flow measurement and adjustment.

Using anemometer, the inlet air flow will be measured. The anemometer will detect the air velocity in m/s along with the humidity and temperature. After the air velocity is measured, let the system to run for 1 hour (except for the 1st data) before the product is measured. This is because the time required for the process starting from entering the cyclone until the last process before the sample can be taken approximately 1 hour. The cracked nut is transferred into the system using a conveyor with slow speed and the chain process for separation after the cyclone including hydrocyclone and claybath make the time required increase.

3.2.4 Product measurement

The product will be measured using anemometer, a device to determine the air velocity as the air pass through its detector. There are 2 products need to be measure; kernel and shell. The products will also being taken 3 times and the average is calculated. Same as the load, time period for the collection of product will be within 5 seconds. The product at the kernel chamber will be checked before the weight being measure. Any dirt such as small rock and shell will be removed first. The product that should be measured is only the kernel. This indicates the separation efficiency to get the pure kernel. Any change on the kernel production will affect the efficiency. Higher kernel produce means the efficiency is high. The weight of the shell product will be directly measure.

3.2.5 Analysis

Average data is calculated for each data taken. The test will be conducted with different amount of load. The graph of kernel production versus air velocity will be plotted for each load. The maximum air velocity will be determined from the graph. The installment of additional cyclone fan to increase the inlet air velocity can also be determined whether it is required or not. Any reduction of the kernel production after the max point in graph indicates that the velocity is too high and the addition of cyclone fan is not required.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result

4.1.1 Effect of inlet air velocity

Table 1 and 2 compare the load of cracked nuts entering the cyclone for separation of kernel and shell at the rate is 0.4 kg/s and 0.3 kg/s respectively. The entering load also contain small amount of fiber, small rock, and soil and will be consider as dirt. As expected, the production of kernel and shell depend on the inlet air velocity of the cyclone separator. The ideal inlet air velocity also changes if the load entering is changed.

Table 4.1: Kernel and shell production with various air velocity for 0.4kg/s load entering the cyclone separator

No	Air velocity (m/s)	Kernel production (kg/s)	Shell Production (kg/s)
1	9.0	0.16	0.06
2	10.0	0.19	0.06
3	11.0	0.20	0.08
4	11.5	0.24	0.08
5	12.0	0.20	0.12

Table 4.2: Kernel and shell production with various air velocity for 0.3kg/s load entering the cyclone separator

No	Air velocity (m/s)	Kernel production (kg/s)	Shell Production (kg/s)
1	9.0	0.12	0.040
2	10.0	0.14	0.057
3	11.0	0.13	0.060
4	12.0	0.12	0.064

The current inlet air velocity used by the system at the plant is 11 m/s and the current production of kernel and shell for 0.4 kg/s load is 0.2 kg/s and 0.08 kg/s respectively. From the data, dirt of the current production is 0.12 kg/s. The production of kernel and shell for 0.3 kg/s is 0.13 kg/s and 0.06 kg/s respectively and the dirt is 0.11 kg/s. The dirt also contain small amount of cracked kernel and shell. This due to the cracked kernel and small particle of shell which is lighter tends to blown with the dirt inside the cyclone separator. The pattern of the data can be seen in the graph below:

a) Kernel Production vs air velocity for 0.4 kg/s load.
b) Shell production vs air velocity for 0.4 kg/s load
c) Kernel Production vs air velocity for 0.3 kg/s load.
d) Shell Production vs air velocity for 0.3 kg/s load.

4.1.1.1 Kernel Production vs air velocity for 0.4 kg/s load.

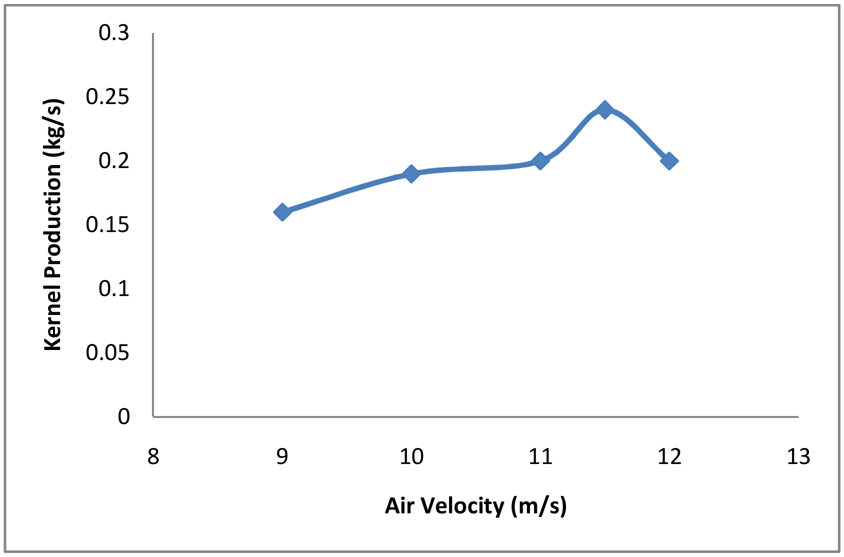

Figure 4.1: Kernel Production vs air velocity for 0.4 kg/s load

Figure 1 shows the production of kernel with certain inlet air velocity. At the beginning of the graph, the production of kernel increase as the inlet air velocity increase. This pattern supports the fact that the efficiency of the cyclone separator depend on the inlet air velocity. At 9 m/s inlet air velocity, the kernel production is low due to the existence of some dirt and shell in the product. Production of kernel increases gradually for each air velocity until 11.5 m/s which is the highest peak. This peak is the best velocity which will give the high production of kernel due to high efficiency. The production is decreasing after for 12 m/s. The kernels tend to follow the inertia of the blown air if the air velocity is too high. In this case, 12 m/s of inlet air velocity is too high for the system and will reduce its efficiency.

4.1.1.2 Shell production vs air velocity for 0.4 kg/s load.

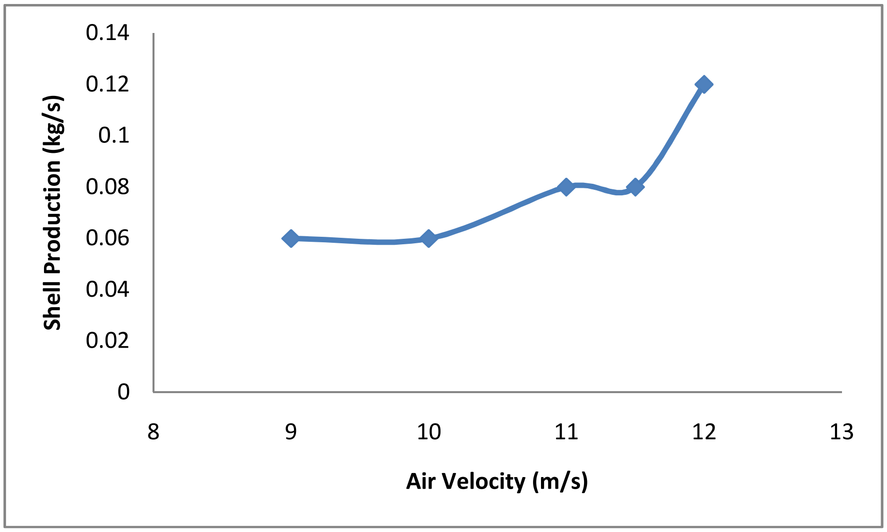

Figure 4.2: Shell Production vs air velocity for 0.4 kg/s load

The productions of shells suppose to increase as the air velocity increase. The experimental data as in figure 2 show the relation of the shell production and air velocity. For 9 – 12 m/s air velocity, the production increase gradually. As for 12 m/s, the inlet air velocity is too high for the system. Total productions of shells increase due to the addition of small or low density kernel which blown away inside the cyclone separator and mix with the shell. At ideal inlet air flow rate (11.5 m/s), the data only have slightly change of kernel production. It means that the highest efficiency has already achieves between 11 m/s and 11.5 m/s for shell production.

4.1.1.3 Kernel Production vs air velocity for 0.3 kg/s load.

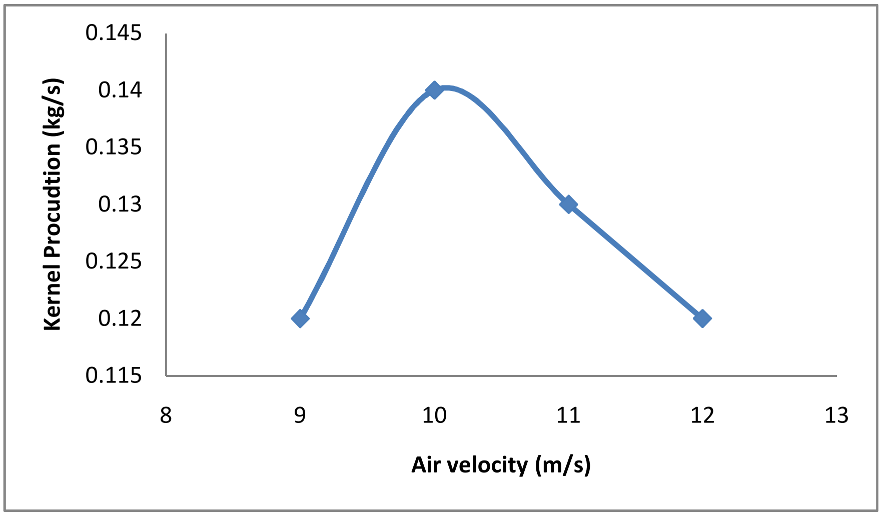

Figure 4.3: Kernel Production vs air velocity for 0.3 kg/s load

Same compare to the graph pattern for load of 0.4 kg/s for kernel production, this figure 3 graph pattern keep increasing until 1 point it will start to decrease. At 9 m/s air velocity, the efficiency is low which make the kernel production low due to the production have many shell and some dirt. The ideal air velocity is at 10 m/s which give 0.14 kg/s kernel production and highest efficiency. Higher inlet air velocity to the system will reduce the separation efficiency and reduce the kernel production. Current air velocity used by the cyclone at the plant is 11 m/s and it is not the best velocity. 10 m/s air velocity should be used.

4.1.1.4 Shell production versus air velocity for 0.3 kg/s load.

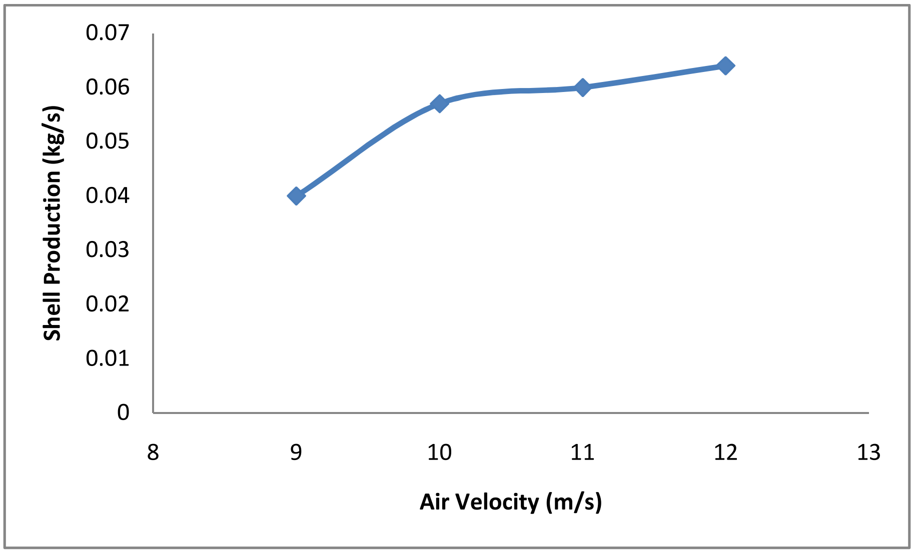

Figure 4.4: Shell Production vs air velocity for 0.3 kg/s load

Shell produce increase as the air velocity increase as shown in figure 4. At 9 m/s the production is low due to low efficiency. At ideal inlet air flow (10 m/s), the pattern shows big changes in the production. For 10 m/s to 12 m/s, the production of shell slightly increases. Increases in the air velocity after 10 m/s will make the kernel inside the cyclone tend to follow the inertia and resulting increasing of shell produced. This will make the kernel production decrease and so the efficiency of separation will also decrease.

4.2 Discussion

4.2.1 Production Change

Table 4.3: Production change for 0.4 kg/s load

Current production/month	After optimization	Difference
518.4 MT/month	622.08 MT/month	**+103.68 MT/month**

Current inlet air velocity used by the system is 11 m/s. Using this speed by assuming the load are constant in a month, the production of the kernel is 0.2 kg/s and converting to month will become 518.4 MT/month. If the speed is adjusted into 11.5 m/s, the kernel production per month will increase to 622.08 MT/month. This makes the difference of 103.68 MT/month production of kernel using different inlet air flow.

Table 4.4: Production change for 0.3 kg/s load

Current production	After optimization	Difference
336.96 MT/month	362.88 MT/month	**+25.92 MT/month**

For 0.3 kg/s load, the pattern is about the same where current inlet air velocity just give the production of 336.96 MT/month kernels and the ideal inlet air velocity which is 10 m/s will produce 263.88 MT/month. The difference is in production is 25.92 MT/month. The difference is small due to lower load capacity entering the system. This load capacity will only be process when there is shortage in fruit supply due to palm fruit season (mainly in February).

4.2.2 Profit change

From the Malaysian Palm Oil Board official website last update on 7 April 2010, kernel price for Mac 2010 is RM 1533.50/MT. Table below compare the price of sold kernel according to load capacity. Current production of kernel for 0.4 kg/s and 0.3 kg/s is RM 794,966.40/month and RM 516,728/month respectively. After the optimization, the profit increase to RM 1,015,299.68/month and RM 556,476.48/month respectively. Load capacity of 0.4kg/s show large difference in the profit of the kernel. The company can get more profit up to RM 220,333.28/month if the best inlet air velocity is used by them. For 0.3 kg/s load, the profit difference before and after optimization is way to smaller than 0.4 kg/s load but the value of RM 39,748.32/month will still be considered as high. Considering from the company start operate in January 2002 and assuming that the load is constantly 0.4kg/s, price of kernel is constantly RM 1533.50/MT and the inlet air velocity has never been change since start operate, total of profit wasted by the company is about RM 19,000,000.00.

Table 4.5: Profit change for 0.4 kg/s load

Current production profit	After optimization profit	Difference
RM 794,966.40/month	RM 1,015299.68/month	**RM 220,333.28/month**

Table 4.6: Profit change for 0.3 kg/s load

Current production profit	After optimization profit	Difference
RM 516,728.16/month	RM 556,476.48/month	**RM 39,748.32/month**

4.2.3 Efficiency reduction cause

There are several factors that reduce the efficiency of the separation process:

i. Partially cracked nut
ii. Inlet load component
iii. Airlock leakage
iv. Size frequency of kernel
v. Type of fruit

4.2.3.1 Partially cracked nut

Nut entered the nut cracker will be cracked before entering the cyclone. Perfectly cracked nut can easily separate into kernel and shell inside the cyclone. Problem occurs when the nut cracker did not perfectly crack the nut resulting partially cracked nut or did not crack at all. There will also over-cracked nut resulting destroyed kernel inside. The destroyed kernel can't be recovered and will be considered as dirt. Half cracked kernel has a low chance to be recovered inside the cyclone. Mixture of all these kind of nut will reduce the separation efficiency. Cyclone has low separation efficiency for small particle.

4.2.3.2 Inlet load component

Before entering the system, the nut will be crack using ripper mill resulting mixture of kernel, shell and small amount of fiber. The efficiency will be reduced if the are other component exist within the load. These particles mostly are soil and small rock. The soil will be separated at the claybath process after the cyclone but the rock will remain within the product. Small rocks will go either to shell product or kernel product. It will not make any problem if the small rocks go to the shell but the existence of small rock within the kernel will disturb the price of the kernel.

4.2.3.3 Airlock leakage

Cyclone airlock leakage will result in decreasing in cyclone collection efficiency and decreasing in conveying velocity at the pickup point. Air leakage will disturb the formation of centrifugal force inside the cyclone. As more air leak, the centrifugal force inside the cyclone will reduce. Separating the load entering the system may require higher centrifugal force. When leakage occurs, smaller particle that suppose to be blown within the air will not have enough inertia and will be drop into the wrong area. Total product at the kernel part will increase but the purity of kernel will reduce due to existence of dirt. Kernel produce will have more shell. Increase the inlet air velocity using additional cyclone fan will make thing worst where another leakage may occur.

4.2.3.4 Size frequency of kernel

Separation is easy if the size of the kernels is same. But in reality, the size of the each of the kernel is different. Its size may depend on the type of the fruit but nut from the same type of fruit also produce difference size of kernel. Larger kernel will be easy to be separated compare to the smaller kernel due to higher efficiency of the cyclone to separate larger particle. Separation can be made using claybath because the density of the kernel remains the same although the size is different. Inside the cyclone, size of the kernel give has higher effect compared to the density.

4.2.3.5 Type of fruit

Types of fruit determine the size of the nut. Currently, companies used to accept 2 type of palm fruit; Dura and Tenera. Dura has a high ratio of fibre, short fibrous strands generally with high oil content, large size nuts with thick shell and numerous multi kernel nuts. Tenera has a low ratio of nuts to fibre, long fibrous strands generally with lower oil content and small size nuts with thin shell and a tuft at one end. Dura has large nut but tenera has smaller nut. This difference in size will slightly disturbing the nut cracking process. The kernel may not crack at all, partially cracked or over-cracked. Ratio of kernel produce per load will be reduced.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The ideal inlet air velocity vary depend on the load entering the system. In this company, the process mostly is 0.4 kg/s. Load will only reduce to 0.3 kg/s when low fruit production season mostly on February every year. Current inlet air velocity used by the company is 11 m/s and it was not being adjusted since 2002. For 0.4 kg/s load, the best inlet air velocity is 11.5 m/s and for the 0.3 kg/s load, the best inlet air velocity is 10 m/s. At this air velocity, the production of kernel and shell will increase. As the production of shell increase, the burning fuel will increase.. As the separation efficiency increase, the kernel product and quality will increase and the profit will also increase. For 0.4 kg/s load, the company can get RM 220,333.28 more per month. The installation of additional cyclone fan does not give much impact to the production of kernel and separation efficiency.

5.2 Recommendation

Separation efficiency of the kernel and shell can be increased if additional separation process is done. Multi cyclone or another separation method such hydrocyclone and claybath can be use after the first cyclone so the product will once again gone through the separation process. Research can be made to set the additional separation process to its max separation efficiency.

The inlet air flow rate should be adjusted according to the load enter. Load indicator should be installed so the air velocity can easily be adjusted. If the load indicator cannot be installed, manual measurement of the load also can be done by the worker. The worker need to check the load enter regularly and adjust the inlet air velocity if needed.

Efficiency of the nut cracker is low if the loads enter is high. So, reducing the load inside the nut cracker will give a better cracking efficiency and reducing the kernel losses. Reducing the nut entered the cracker may resulting the excess amount of nut which need to be cracked. So additional nut cracker is recommended to prevent this problem from occur.

It is also recommended to change the cyclone airlock because the leakage of the airlock always occurs. If the leakage is noticed early by the worker, the production and profit loss will be minimum. If it is not noticed early, the separation efficiency will reduce for a long time and profit loss will be high. By changing the air lock, this problem can be solved.

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APPENDIX A

Daily Palm Oil Market Price

LAST UPDATE : APRIL 26, 2010 @ 16:20

Crude Palm Oil (LCL DEL RM/MT)													
Mth	North	South	Central	E.Coast	P/Mal	Highest	Lowest	Sabah	Highest	Lowest	Mal	Highest	Lowest
April	2,531.00	2,529.00	2,538.00	NT	2,531.00	2,575.00	2,510.00	2,502.50	2,520.00	2,490.00	2,522.00	2,575.00	2,490.00
May	2,510.00	2,534.50	2,540.00	2,545.00	2,535.00	2,570.00	2,495.00	2,448.00	2,505.00	2,445.00	2,468.00	2,570.00	2,445.00
Jun	NT	2,518.50	2,495.00	NT	2,515.50	2,520.00	2,495.00	NT	NT	NT	2,515.50	2,520.00	2,495.00
July	NT	2,535.00	2,495.00	NT	2,530.00	2,535.00	2,495.00	NT	NT	NT	2,530.00	2,535.00	2,495.00

Palm Kernel (LCL EX MILL RM/MT)									Palm Kernel (LCL DELD RM/MT)				
Mth	North	South	Central	E.Coast	P/Mal	Highest	Lowest		Sabah	Highest	Lowest		
April	1,506.50	1,520.00	1,530.00	NT	1,515.50	1,530.00	1,500.00		1,458.00	1,465.00	1,445.00		
May	NT	1,530.00	NT	NT	1,530.00	1,530.00	1,530.00		NT	NT	NT		
Jun	NT	1,470.00	NT	NT	1,470.00	1,470.00	1,470.00		NT	NT	NT		
July	1,510.00	1,470.00	NT	NT	1,473.00	1,510.00	1,470.00		NT	NT	NT		

Resource from:

Lembaga Minyak Kelapa Sawit Malaysia
MALAYSIAN PALM OIL BOARD (MPOB)

APPENDIX B

Experimental Pictures

Figure B1: Cyclone in Industry

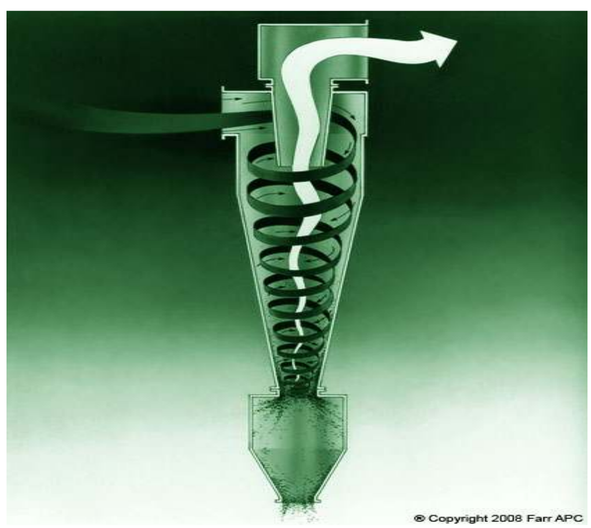

Figure B2: Flow of Air Inside Cyclone

Figure B3: Oil Palm Tree

Figure B4: Oil Palm Fruit with fruit bunch

Figure B5: Oil Palm Fruit

Figure B6: Oil Palm Fibre after Separation

Figure B7: Cross-section of Oil Palm Fruit

Figure B8: Oil Palm Shell after Separation