Combined Pulverisation and Drying of Oil Palm Biomass in a Single Machine: Nanomass Technology System

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INTRODUCTION

The Malaysian palm oil industry is growing rapidly, becoming a significant commodity in this country. In 2020, there were almost 5.9 million hectares of land planted with oil palm in Malaysia with a total of 457 palm oil mills. These mills received 96.97 million tonnes of fresh fruit bunch (FFB), producing about 19.14 million tonnes of crude palm oil (CPO) (MPOB statistics, 2020). Besides producing palm oil and palm kernel, these palm oil mills also generated an abundance of by-products such as empty fruit bunches (EFB), mesocarp fiber (MF), palm kernel shells (PKS), and palm oil mill effluent (POME). On the other hand, oil palm fronds (OPF) and oil palm trunks (OPT) are generated at the oil palm plantation from the pruning and replanting processes. These oil palm biomass (OPB) could become alternative materials for other industries such as for the production of biomass pellets, bioplastics, bio-composites, second generation biofuels, green chemicals, *etc*. For example, OPB has the potential to be utilised as renewable energy to produce synthetic biofuel, power generation (Loh, 2017), bio-ethanol production from lignocellulosic waste (Yanni *et al*., 2013), biocomposites (Shinoj *et al*., 2011), and for mulching to increase the FFB yield in plantations (Anyaoha *et al.*, 2018). The OPB has an advantage since it is abundantly available, renewable, and can be converted to be used as cheap feedstocks for other applications, thus reducing the environmental impact of biomass disposal. To increase oil palm biomass utilisation, efforts have been undertaken to investigate pretreatment and pre-processing technologies, particularly on size and moisture reduction for better handling, storage, and suitability for their intended application.

OPB has the characteristics of high moisture content, bulkiness, and low density which hinders and affects their utilisation rate as a feedstock for other industries. This results in issues related to its collection, handling, transportation, and storage. Thus, pre-treatment and pre-processing are important factors, particularly on size and moisture reduction aspects to ensure their economic feasibility. Size and moisture reduction are considered as some of the most energy and cost-intensive operations in converting raw biomass to become feedstock for other industries (Hanning Li *et al*., 2012, Venkata *et al*., 2009). In general, the size reduction for oil palm biomass involves the cutting, shredding, chipping, hammer milling, and grinding processes. The selection of the equipment depends mostly on the type of biomass and its intended application. Since the OPB collected differs in shape, size, and density, thus it needs to be processed to a desirable size and format for ease of handling, transportation, and storage. The size, shape, and moisture content of biomass also play an important role in the effectiveness of subsequent processes, particularly for conversion and combustion processes. For the pulping process, the biomass should be of a uniform size of 2.5 cm x 5 cm with a thickness of 6 mm, for ethanol production (1-6 mm), pyrolysis (<3 mm), pellet, and briquette (3 to 8 mm) and co-firing with coal (0.8-6 mm) (Ladan *et al*., 2006). For syngas, pyrolysis, and pellet production, the biomass should have a moisture content below 15%, 10%, and 10%, respectively (Fagernas *et al.,* 2014). In addition, for long-term storage, biomass with a low level of moisture is required to ensure less deterioration of biomass quality. This moisture reduction is carried out through the drying process. Mechanical drying such as by using an EFB shredder and press is only capable of reducing the moisture content in OPB to around 45%. Thus, thermal drying which normally involves external heat is required to reduce the moisture content of biomass to low levels. Thermal drying, either through direct or indirect heating incurs high fuel costs and takes around a few days or minutes depending on the drying technology. Several proven technologies such as rotary dryer, fluidised bed dryer, tray dryer, flash dryer, and stationery bed dryer have been used by the biomass industry to dry oil palm biomass. The most frequently used drying mediums are hot air, hot air mixed with steam, vacuum, and superheated steam (Fagernas *et al.,* 2014, Hanning Li *et al*., 2012). The selection of the dryer depends on the type and size of the biomass, with the rotary dryer being the most used dryer for biomass. It makes use of hot air or boiler flue gases to dry the OPB in the form of chips from OPF, OPT, and EFB fiber. The selection of size reduction and drying processes depends on the type of materials, their characteristics, end-use applications as well as their energy requirements.

Currently, several available biomass conversion technologies have been developed such as gasification, torrefaction, pyrolysis, biomass combustion, and pelletizing. Most of them require a specific feedstock specification in terms of size and moisture content. Therefore, matching the right feedstock specification with the right technology may increase the utilisation of OPB.

NANOMASS TECHNOLOGY SYSTEM (NTS)

Figure 1 shows the schematic diagram (a) and photo of the NTS Plant (b). The NTS plant consists of a feeding screw conveyor with a rotary airlock, an implosion chamber, an air classifier, a blower, a cyclone with a rotary airlock at the bottom, and a product conveyor.

The feeding conveyor, the implosion chamber, and the blower motor are equipped with a variable frequency drive (VFD) whereby the speed of the motors can be adjusted.

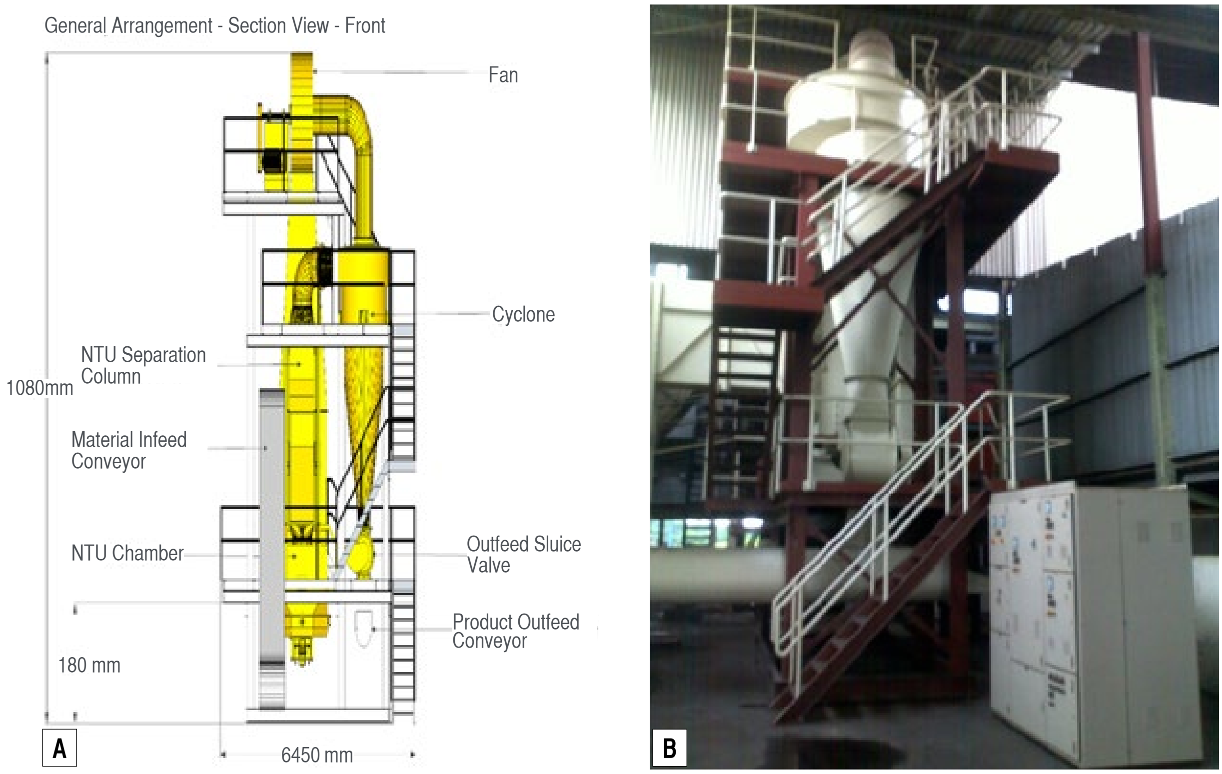

Figure 1. NTS plant (A) schematic diagram and (B) photo .

Below is the power of the motors for the NTS plant:

Feeding conveyor (scraper)	5.5 kW
Air lock (2 units-3kW)	6.0 kW
Product conveyor (screw)	3.0 kW
A cyclone blower	22.0 kW
NTS main unit (implosion chamber)	132.0 kW

The system can pulverise and dry various types of material with a maximum feeding size of 3 inches in diameter and a moisture content of up to 70%. The capacity of the system is 2.4 t hr^{-1} depending on the material type.

WORKING PRINCIPLE

The working principle of the NTS plant is by high-speed rotation of the rotor (chains) in the implosion chamber. This will create air turbulence and a standing wave that resonates within the implosion chamber. The material that enters the chamber will be crushed and fractured repetitively by the chain against the wall and crushed against each other, thus becoming smaller and finer in size. At the same time, the standing wave resonates causing the molecular structures of the material and the moisture particles within to oscillate at high frequency which results in moisture bubbles inside the material expanding to the extent that an implosion occurs and the material disintegrates, becoming fine powder, while the moisture turns into water vapor. The heat generated by the kinetic energy from the chain's speed evaporates the material's moisture. The fine, dry powder is then lifted through the classifier and then to the cyclone before being discharged into the product conveyor. By varying the speed of the rotor system, the standing wave pattern and frequency will also change, making it possible to disintegrate various types of materials such as the disintegration of OPB into dry fine particles. *Figure 2* shows the inside of the implosion chamber with a series of chain that rotates at high speed to crush the materials as well as creating a standing wave.

Figure 2. The implosion chamber.

THE TIP SPEED OF THE CHAINS

Based on the rotor speed, which runs in the range of 850 to 2400 rotation per minute (rpm) and the diameter of the chain (152.4 cm), the linear speed or the tip speed of the chain inside the implosion chamber can thus be calculated as below.

Linear speed = π x chain diameter x rotor speed (rpm)

TABLE 1. THE ROTOR SPEED WITH THE TIP SPEED OF THE CHAIN

Rotor speed (rpm)	Chain's tip speed (km hr^{-1})
1000	287.5
1200	345.0
1400	402.5
1600	460.0
1800	517.5
2000	575.0
2200	632.5

Table 1 shows the material that enters the implosion chamber will be crushed by the high speed of the chain and by centrifugal force that throws the material onto the wall. This action will be repeated till the material becomes very fine and dry, which could then be lifted by the air suction through the classifier and discharged at the bottom of the cyclone.

THE TEMPERATURE IN THE IMPLOSION CHAMBER (NTS UNIT)

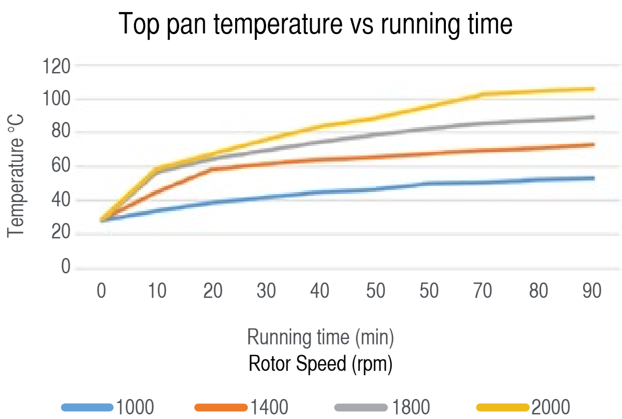

Figure 3. Temperature of the top pan for NTS unit on dry running.

Figure 3 shows the temperature of the top pan for the NTU unit when running empty. It shows that the higher the speed of the rotor, the temperature of the pan also increases with time. For a rotor speed of 1000 rpm, the highest temperature attained was 53°C, whereas for 1400 rpm, 1800 rpm, and 2000 rpm the highest temperatures after 90 min were 73°C, 89.2°C, and 105.8°C, respectively. However, when running with feeding material such as PKS, the highest temperature for the top pan is around 98.6°C. This might be due to some heat used to dry the material absorbed by the material during discharge onto the product conveyor. This high temperature is created by the kinetic energy from the high speed of the chain that creates high-velocity air inside the implosion chamber. This high air velocity and temperature cause the fine particles to dry very fast.

THE YIELD OF BIOMASS MATERIAL

The NTS plant has been tested using different types of OPB at low and high speed and the yields are shown in *Table 2*:

TABLE 2. YIELDS OF BIOMASS FROM THE NTS PLANT AT DIFFERENT MACHINE SPEEDS

Biomass type	Yield at 1020 rpm (%)	Yield at 2000 rpm (%)
Palm Kernel Shell	100	100
Mesocarp Fiber	50	50
Shredded EFB	20	40
OP Frond chips	40	n/a

PKS can be pulverised completely even though the machine runs at a low speed of 1020 rpm. For mesocarp fiber, only 50% of the mesocarp is pulverised into powder while another 50% turns into a small fine fiber, even though the machine runs at a higher speed of 2000 rpm. Whereas for EFB fiber, a higher machine speed will slightly increase the powder yield obtained from 20% to 40%, while the rest turns into a small dry fiber. The possible reason for the low yield for the EFB and mesocarp fiber might be due to the fiber itself which is light. When subjected to crushing and drying by the NTS, it becomes smaller, shorter, and lighter and is thus easily lifted and separated by the air stream into the product outlet. The low yield could also be due to some lengthy fibers adhering and clinging to the chain, thus reducing the crushing impact of the ring into the fiber. On the other hand, the mixture of mesocarp fiber with PKS at a ratio of 1:1 could be pulverised completely. The system is capable of producing dry PKS powder at an average MC of 9.8% independent of its initial moisture. Whereas for shredded EFB and OPF chips, the MC can be reduced to 18% and 22% from initial moisture contents of 45% and 68%, respectively. *Figure 4* illustrates the photographs of the PKS dry powder, fine EFB particles, and fine OPF from the NTS plant.

Figure 4. Products from the NTS plant, (A) PKS powder, (B) EFB, and (C) OPF.

ENERGY CONSUMPTION

The NTS plant consumes about 95 kWhr of electricity to dry and pulverize 2.5 t hr^{-1} of PKS. For shredded EFB, the energy requirement is slightly higher at about 136 kWh for the capacity of 1.5 t hr^{-1}, whereas for OPF chips and mesocarp fiber, the energy consumption was on average 110 kWhr for 1.5 t hr^{-1}capacity. The energy requirement by the NTS plant is low compared to the energy consumption used by a hammer mill as well as a knife mill which are around 130 kWh and 200 kWh, just to reduce 1 t of wood chips to a particle size of 1.6 mm and 0.3 0.15 mm, respectively (Tumuluru *et al*., 2014, Sang-Kyun Han *et al*., 2014).

SIZE DISTRIBUTION OF THE DRY POWDERED PALM KERNEL SHELL (PKS)

Figure 5 shows the size distribution of the dry powdered PKS obtained when the machine runs at different speeds.

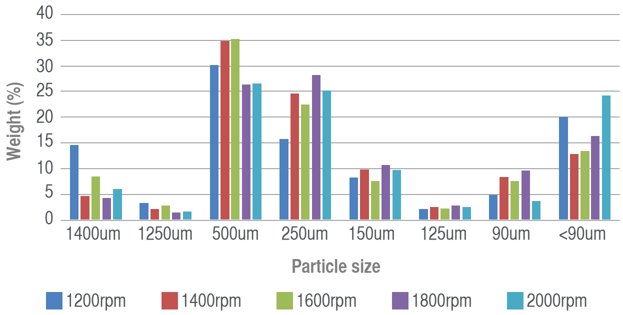

Figure 5. *Size distribution of the PKS powder at different machine speeds.*

Most of the PKS powder obtained has a size range of 150 µm to 500 µm with an average quantity of 54% to 70%, while some are below 90 µm with a quantity in the range of 13% to 24%. The size distribution of the PKS is mostly affected by the lifting air velocity generated by the cyclone blower through the classifier and is not affected by the rotor speed of the NTS main unit. The PKS feeding material has a size in the range of 2.3 mm to 6.7 mm with an average moisture content of 18.6%, while the dry powdered PKS has a moisture content of 9.8%. The average for bulk and tapped density of powdered PKS is 650.0 kg m^{-3} and 713 .0 kg m^{-3}, respectively.

POTENTIAL MARKETS FOR NTS PRODUCTS

The success of the NTS system in converting oil palm biomass into dry-fine particles or powder will open up new potential markets such as:

1. Biomass powder to replace the existing MF and PKS as boiler fuel for heat and power generation using a powder/dust burner. Since the fuel is in the form of fine particles and has a low moisture content (<10%), complete combustion with less soot and unburned particles can be expected.
2. The biomass powder can be mixed with POME for biofertiliser application through the composting process. The process will be much faster and effective due to the small particle size (high surface reactivity), thus a shorter processing time can be expected resulting in less production cost.
3. Biomass powder can be used as a feedstock for the production of second generation biofuel as well as fine chemicals extraction. The fine powder has a high surface area, thus a better and faster reaction could take place (such as bio-ethanol, pyrolysis, gasification, xylose, cellulose, and lignin extraction, *etc*.).
4. These fine particles can also find ways for pellet production and as a filler for producing the bio-degradable plastic and wood-plastic composites.
5. Animal feedstock with nutrient correction.

CONCLUSIONS

The NTS plant has demonstrated its capability and suitability in pulverising and drying oil palm biomass into a fine dry fiber/powder in a single machine. The system is simple with a single process to perform the pulverisation and drying operations without additional heat requirements. Thus, it requires less energy compared to the conventional process that involves many process steps and multiple types of machinery to produce a similar product. This indirectly reduces the labor and energy cost for size reduction and drying of oil palm biomass. With the low cost of biomass powder production, together with the right size and moisture content, the utilization of the oil palm biomass as a feedstock for other industries could be increased.

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