

Thailand's first continuous steam explosion prototype debut

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Abstract

The world's first three largest producer and exporter of palm oil today are Indonesia, Malaysia and Thailand. In 2011, Thailand has produced palm oil up to 1,450 million tones for national consumption and export. It is estimated every year of 2, 1.7, and 4.9 million tones of wastes in the form of oil palm trunks, fronds and empty fruit bunches consecutively. Some wastes are treated as biomass or even burn, but still many of them create problems of environmental. Palm trunk and frond consists of huge amount of fiber while it can be transformed because the fiber has cellulose in it. Steam explosion pretreatment is a technique to conduct and enhance the accessibility of the oil palm lignocellulose. A continuous steam explosion prototype has been designed and built in order to separate lignin from cellulose and hemicellulose. The outcome fibers are tremendously useful as commencing material for particles board industries, biochemical as monomer and polymer, biofuel as ethanol, and abundant of specialty chemical such as green solvent, lactic acids, or many pharmaceutical precursors.

Keywords: steam explosion, oil palm trunks, fronds, lignin, cellulose and hemicellulose.

1. Introduction

Steam explosion generally refers to the process of exposing fibers to high-pressure steam (typically 15-30 bar g) for a period of 1 - 10 minutes and then explosively discharging the product to atmospheric pressure. The main components of fibrous materials, such as wood and straw, are cellulose, hemicellulose, and lignin. In nature, the lignin acts as glue and binds the cellulose chains together. In order to utilize these fibers, it is necessary to separate the lignin from the cellulose. In the past, it has only been possible to break the bonding between the cellulose and the lignin through very expensive and highly polluting chemical pulping processes. However, the steam explosion technology can possibly break the bond between the cellulose and the lignin using only high pressure steam.

Batch steam explosion was commercially introduced in 1931 with the introduction of the Masonite process for the production of fiberboard. In the 1970's and 1980's, several commercial and academic organizations began conducting research and development which explored other applications for steam explosion, including the production of cattle feed, ethanol and specialty chemicals from wood fibers. Batch steam

explosion had associated with the certain heat transfer limitations as well as the less critical mass production for industrial scale.

2. From Concept to Real

The continuous steam explosion prototype is designed base on concept of pushing woodchip into a digester, which continuously supplied by a high pressure and temperature of saturated steam or even superheated condition. The woodchip is then cooked inside the digester for such periods of time depend upon the optimized condition for each type of fibrous materials. The cooked woodchip is transferred to an explosion chamber, which located under the digester. Then the woodchip in a control amount is immediately released from the digester through an explosion valve, which open to atmospheric pressure and moving to the special cyclone, which be able to separate the fibers, and released steam effectively. With a rapid change of steam pressure, the woodchip structure (basically consists of cellulose, hemicellulose, lignin etc.) will be molecularly broken down and partially separated into fibers. The outcome fibers are tremendously useful in producing others fiber, monomer, polymer, biofuel and abundant of

specialty chemical such as green solvent, lactic acids, or many pharmaceutical precursors.

The continuous steam explosion machine could be divided into several which are a conveyor module, a feeder module, a digester module, explosion module, steam supply module and control module as shown in figure 1.

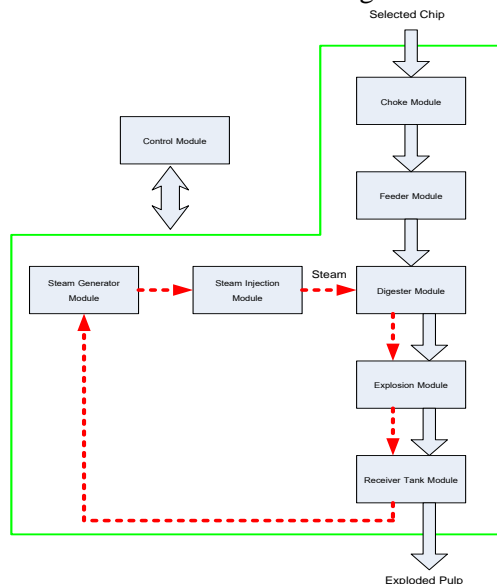


Fig.1 Modules of Continuous Steam Explosion

The conveyor module is used for transporting the small size of wood chip to the feeder module. However, this module has been design to be compatible with a hammer mill. Starting with the oil palm trunks, fronds and empty fruit bunches which are raw material and needs to be broken in small pieces (not bigger than one inches long). The material as a palm trunk can be placed in an adjustable track and gravitationally move to the end of the track. There is a cutting wheel connected to the end of the track and used to cut the material into small pieces. The cutting speed is between 20 to 30 rounds per minute. The small pieces of material then fall into a hammer mill, which rotates, in high speed. The mill will continuously break the material into the proper size (normally between an quarter to half inch). Then all material will be transferred into a bucket located at the bottom of a vertical belt conveyor. The vertical conveyor composes of many spoon buckets attached to a transmission belt that moving vertically. When the vertical conveyor has been operated, each spoon bucket will bring the certain amount of palm chip to the top of the conveyor. The conveyor will continuously transfer the material to the top at the desired amount. In order to control the percentage of moisture of the material, the water spray nozzles

and moisture sensors has been installed on the top of the conveyor to control and measure the moisture properties of the material before entering to the feeder module.

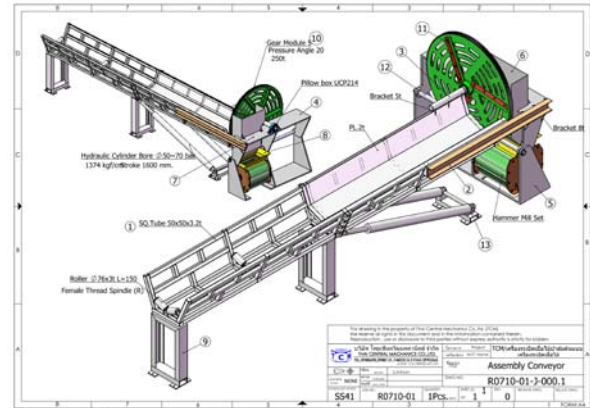


Fig. 2 The cutting wheel and hammer mill

The feeder module is composed of two different sizes of screw feeders. The first screw is conventional, made from rough iron, and used to move the material from the conveyor module to the second screw, which are in perpendicular oriented to each other. The second screw is typical designed to creating high compression ratio for the material. The screw, made from rough iron and special surface coating, is tilt and varying in screw pitch inserting into the octagon shape of screw case. Both screws are controlled and powered by two electrical motors. The high ratio gearbox is also used with the second screw to create high torque to the screw shaft. There is a special designed of mechanical check valve at the end of the octagon screw case as well. This mechanical check valve is used to prevent the back steam pressure from the digester. It is very important to be avoiding back steam pressure that might cause lots of problem if it occurs. There are many little holes around and underneath both of the screw cases. These holes are helpful to allow the overflow of the bio liquid squeezed from palm chips. The bio liquid is one of the unexpected problems happening during the process. It makes palm chip floats over the screws and high-density palm chip cock could not be create at the end of the digester case. Therefore, this bio liquid needs to be removing from the chip cock as much as possible. However, this bio liquid contains so many bio chemical in the form of polymer chain of sugar and it can be utilized by others chemical process in order to create more value of the palm chip. The second screw is

capable of compressing the palm chip material to very high density (2 to 3 kilogram per liters) so that the compressed chip can be push against high steam pressure. However, the strength of the compressed chip will be reduced depend on heat and time it will face at the end of the octagon screw case. Therefore the proper feed rate of the screw feeder is very essential but can be controlled and adjusted by the control module.

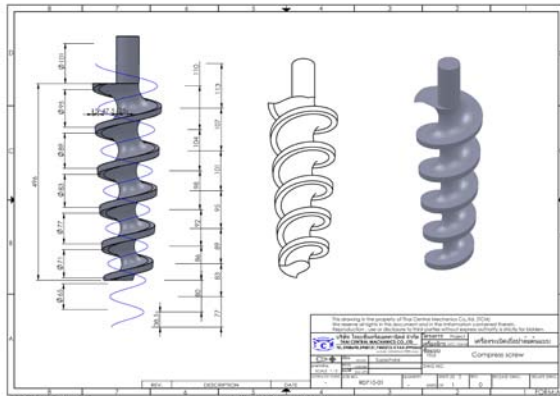


Fig. 3 The tilt screw feeder

The digester module is designed in the way that it could retain steam pressure and temperature effectively but has less mechanical parts inside. Therefore, the digester is made in the form of vertical cylinder; palm chips will be moved from top to bottom by gravitational force. The digester is made from rough iron pipe with 20 mm thick, it's diameter is 300 mm, with 1800 mm long and equipped with several sensors such as temperature transmitter, pressure transmitter, and level transmitter. This digester's dimension is capable of flowing palm chips at the 300 – 500 kilograms per hour. The structural finite element program is used to verify and simulated the durability of the digester. The maximum stress and strain concentration obviously occurs at the middle of the cylinder. However, it is designed to stand for high steam temperature and pressure. The operating saturated steam pressure is designed to the maximum of 40 bar G and 50 bar G hydraulic pressure has been tested for the safety issue. A sheet insulator with high heat conduction value is used and wrapped around the outer case of the cylinder in order to preventing heat loss.

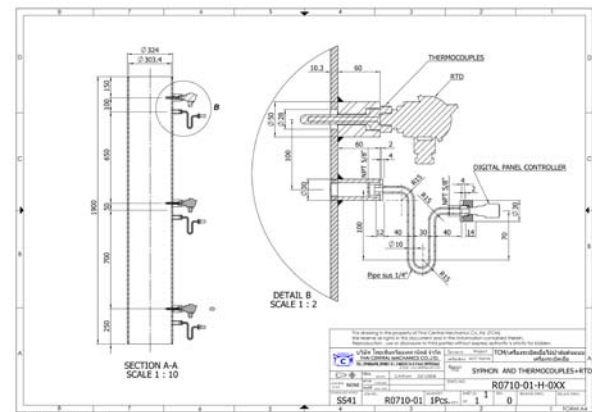


Fig. 4 The digester module

The explosion module is considered to be the essential of the machine prototype. The module is made from stainless steel in the shape of cylindrical drum. There is a rotating blade at the bottom of the drum and capable of pushing cooked chip into an explosion chamber. The blade is driven by an electrical motor underneath and special mechanical seal has been used to prevent the high pressure steam leaking. The chamber is also connected to an explosion valve, which is special designed and built for releasing palm chip to an ambient temperature and pressure. When the palm chip has already been cooked inside the digester, the cooked chip would be continuously falling into the rotating blade. The certain amount of the cooked chip will be push to the explosion chamber and ready to be release to the ambient through an explosion valve. The explosion valve is also special designed and built. The valve has to be opened and closed in short period of time; therefore, 4 bar G air pressure has supplied to the pneumatic valve to guarantee the explosion state. Special material and surface coating has been selected to build the valve so that it can stand for heat energy generated from high temperature and pressure supplied steam during the explosion process.

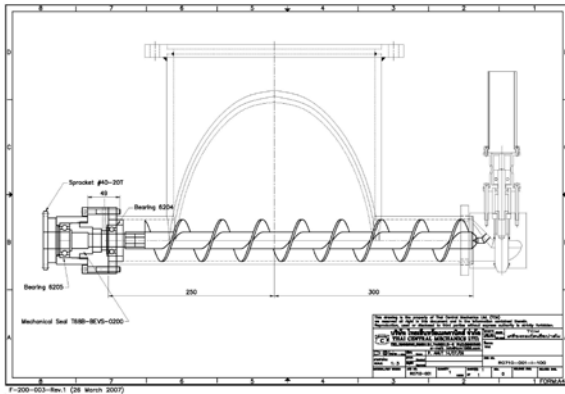


Fig. 5 The explosion module

The continuous steam explosion machine prototype has to be supplied by high-pressure steam. The supplied steam could be saturated steam or superheated depend on explosion conditions. Therefore, the desuperheated system, which composes, of a desuperheated valve, high-pressure water valve, and piping accessories has been installed to the machine prototype. The desuperheated valve is used to allow high-pressure water from a feed water pump to mix with the superheated steam. The mixing can reduce energy from the superheated to the saturated steam or even steam mixer depends on a control command from the control module. The desired steam conditions (pressure and temperature set point) then are fed to the digester module.

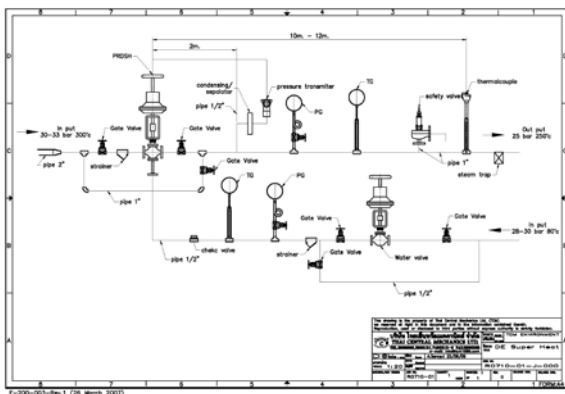


Fig. 6 The steam supplied piping diagram

Once all module has been fabricated and assemble for machine prototype, the machine is installed and commissioning at the palm oil extracting factory due to an available high pressure steam supply from the steam generator.



Fig. 7 The steam explosion prototype

3. Optimization approach and results

A severity factor combining temperature and time has been developed and has proven to be useful in comparing different steam treatment conditions. This steam treatment severity factor, also known as the reaction ordinate (Ro), is defined, in the absence of a catalyst, as:

$$Ro = t \cdot \text{Exp} [(T-100)/14.75] \quad (1)$$

where,

Ro = the severity factor in minutes

t = the residence time in minutes

T = the steam temperature in degrees C

The severity factor increases exponentially with increases in reaction temperature and linearly with increases in the reaction time

The different steam pressure and temperature along with several detention times are selected and tested on palm material. Table 1 shows some result of percentage of cellulose, hemicellulose and lignin extracting by standard technique conducted in laboratory. It shows a decreasing trend of extracted lignin after higher number of the severity factor. Therefore, further exploration needs to be made in order to maximize the outcomes from the explosion pulps.

	Steam Pressure (Bar G)	Steam Temp (°C)	Residence Time (Min)	Cellulose %	Hemicellulose %	Lignin %
Oil Palm Trunk	20	214	5	16.95	45.30	33.65
		216	10	11.00	29.50	11.90
	25	226	5	13.45	36.40	12.05
		226	10	9.05	27.30	6.45
Oil Palm Frond	20	216	5	11.40	50.05	33.75
		216	10	5.65	33.70	11.90
	25	226	5	6.73	36.37	18.67
		226	10	7.47	42.37	21.40

Empty	20	216	5	11.15	44.50	36.45
		216	10	7.45	32.55	11.85
Fruit Bunch	25	227	5	5.50	34.95	18.55
		227	10	8.80	46.25	31.15

Table 1 Percent of Cellulose-Hemicellulose-Lignin Extracted from Explosion Palm Pulp

4. Conclusions

The continuous steam explosion machine is currently used in industrial and research around the world. Due to its complexity and highly investment of the machine, this technology is not yet introduced in Thailand. However, the advantages of being green technology and broadband outcomes from explosion pulp will attract many investors especially ones in the oil palm business in the near future.

5. Acknowledgement

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7. References

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