Jurnal
Teknologi

Full Paper

RECENT TREND IN RESIDUAL PALM OIL RECOVERY IN A SOLID STATE FERMENTATION

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Article history
Received
6 April 2017
Received in revised form
2 November 2017
Accepted
15 January 2018
Published online
1 April 2018

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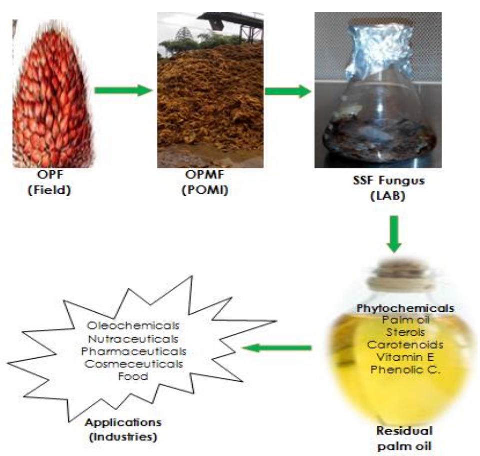
Graphical abstract



Abstract

Production of palm oil from palm oil mill industries has been facing a serious challenge of overcoming the oil loss as a result of the mechanical extraction process limitations, consequently, leading to economic and environmental impacts. Efforts were made to overcome this impasse by mechanical process, dissolve air flotation, solvent extraction and enzymatic treatment. Most of these methods applied are faced with a somewhat drawbacks. In this review, the various methods of residual palm oil recovery were discussed, while presenting a better method that could allow for optimum recovery with less or no environmental impact via microbial means in a solid state process. Biological process in a solid state condition with fungi such as the white rot basidiomycetes is considered the best for future application, due to the natural availability of the fungi and high degrading capability of lignocellulose biomass. This would significantly be of benefit in terms of abating the huge oil palm mesocarp fiber deposition and aid in meeting the environmental requirement of waste consumption from the source.

Keywords: Residual palm oil, Recovery, OPMF, Fungi, Fermentation

Abstrak

Pengeluaran minyak sawit dari industri minyak sawit menghadapi cabaran yang serius untuk mengatasi kehilangan minyak akibat daripada batasan dalam proses pengekstrakan mekanikal, yang membawa kesan kepada ekonomi dan alam sekitar. Pelbagai cara telah dibuat bagi mengatasi masalah ini seperti proses mekanikal, *dissolve air flotation*, pengektrakan pelarut dan rawatan enzim. Sebahagian besar daripada kaedah yang digunakan mempunyai kelemahan. Dalam kajian ini, pelbagai kaedah pemuliharaan sisa minyak sawit telah dibincangkan, disamping membentangkan kaedah yang lebih baik yang membolehkan pemuliharaan optimum dengan kurang atau tiada kesan kepada alam sekitar melalui penggunaan mikrob melalui proses keadaan pepejal. Proses biologi dalam keadaan keadaan pepejal dengan kulat seperti Basidiomycetes kulat putih dianggap yang terbaik untuk aplikasi masa depan, kerana kulat ini wujud secara semulajadi dan berkemampuan tinggi dalam mencernakan biomass lignoselulosa. Ini akan memberi manfaat yang ketara dalam mengurangkan kelapa sawit pemendapan gentian mesokarpa dan membantu dalam memenuhi keperluan penggunaan sisa dari sumber.

Kata kunci: Residual minyak sawit, Recovery, OPMF, Fungi, Penapaian

1.0 INTRODUCTION

Due to the concern for environmental sustainability, pressure has been mounting on palm oil industries to ensure the sustainability of the production path of crude palm oil (CPO). The production; waste evacuation, if not consumed by the industries should be discharged in a way that will not inflict ill to the environment or its eco-resources.

The production process practiced by most palm oil mills is the wet technique, involving the use of steam and water. Major stages chronologically are expressed in Figure 1; sterilization, stripping, digestion, pressing and decanter screening/clarification. Sterilization involves heating the fresh fruit bunches (FFB) by means of steam sterilizers (140 °C and a pressure of 3 x10^5 Pa) for 50 min [1]. The introduced heat, moisture from steam chemically brings about degumming and resin splitting. The success of these stages determines the success of subsequent processes, as the high pressure may cause nut expansion and as pressure goes down, nuts contraction detaches the kernel from shell wall [2]. The effluent discharged at this stage is called sterilizer condensate, which under appropriate operation and management is ~ 0.9 tonnes for every tonne of crude palm oil produced [1].

During the second stage stripping (threshing); the detached fruits are separated from the stalks or bunches, giving out the Empty fruit bunch (EFB). After this stage, the fruits undergo digestion. This process involves reheating for about 80-90 °C in order for the mesocarp to be loosened from the nuts [1, 3]. Here the nuts became shell free with no residual occurrence. This process reduces the viscosity of oil [2]. The obtained oil mash (homogeneous) is sent for pressing. At the screw pressing, the oil is separated from the digested fruit, while getting rid of the mesocarp fiber and the nuts, collectively called the oil palm mesocarp fiber (OPMF)/ palm pressed fiber (PPF)/ pressed cake. The crude palm oil leaving the screw press contains oil, water and solids. In the clarification stage, the mixture is settled and centrifuged, mainly for the removal of water, then to the sludge separator, where the clarification sludge undergoes oil recovery. The final water removal is achieved at the vacuum drying and finally to the storage prior to despatch for refining.

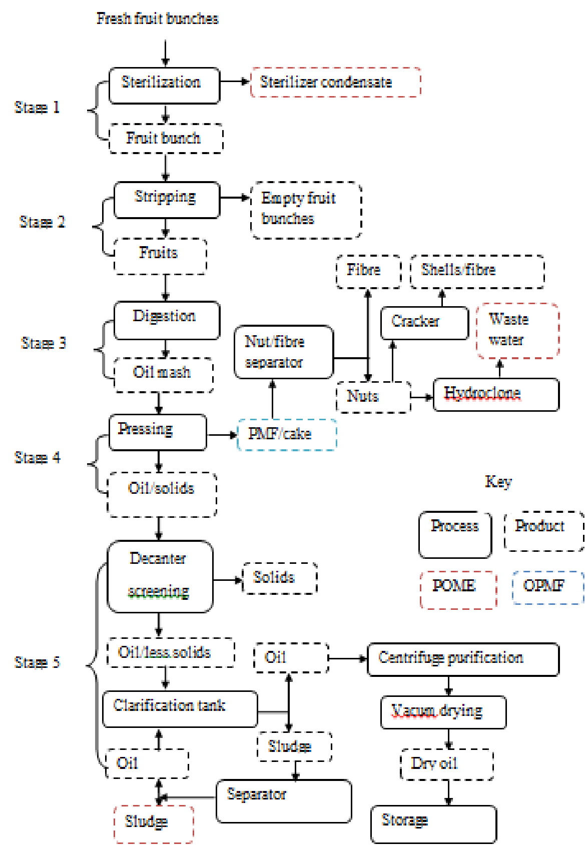


Figure 1 Flow chart of palm oil production and the channels for residual palm oil loss

Generally from the operational stages described above, the points of waste generation are almost the points of oil loss. Various estimations were made regarding the quantity of CPO produced per tonne of FFB and the waste generated. On the average 1t of FFB yields crude palm oil (21 %), palm kernel (6.5 %), empty fruit bunch (23 %), fiber (14.5 %), shells (6.5%), palm oil mill effluent (0.7 m^3) [4]. The present handling method of the solid biomass is either disposed underneath the palm trees or burn in boilers to generate electricity and steam for palm oil extraction [5-7], excess palm kernel shell (PKS) are used for road surfacing in estates [8], while the remaining unused mesocarp fiber and PKS are sold as fuel in the market [9, 10]. The wastes are so huge to be utilized and their presence created a major disposal problem causing pollution and breeding ground for pest.

Studies have showed that out of the mesocarp fiber generated, consistent amount of oil escaped as residual oil [11]. Analysis of such discharged in Malaysia is around 5.0-11.0% [12]. So the oil escaping has now become an inevitable loss by the palm oil milling industry due limitation of the screw press. Recent studies revealed that the recovered oil is even richer than the normal channelled oil in terms of nutritional values. It has been reported that the oil is rich in sterols, carotenoids, tocopherols and tocotrienols [13].

This paper draws together the different methods applied in oil recovery so far, from the physical, chemical and the enzymatic/biological processes currently in use that can increase yield and recovery of residual oil. Limitations and cost effectiveness were also looked upon while conversely presenting a future technology in the recovery of the residual oil by microbial fungi. This process is highly cost-effective and ecologically sound.

2.0 STUDIES ON RESIDUAL OIL RECOVERY

Residual oil recovery is somewhat similar to oil extraction, the line of difference seen mostly when virgin source is used, most often is called extraction. Oil recovery is mostly used to describe oil extraction from waste or what is considered as waste or when the oil is extracted for the second time. Some instances to refer to this are literatures on oil recovery from waste which are on the high side as "recovery" [11, 13-20]. Cheah, Augustin and Ooi [21], described the process as extraction in PORIM Bulletin Titled enzymatic extraction of palm oil, since the palm oil was obtained from Oil palm mesocarp mash which was a virgin source not waste. Reviews from literatures inferred the process as extraction [2, 22, 23]. While the term extraction was used commonly for virgin source, however some authors a times used it as a term to describe residual oil recovery from the waste like palm oil mill effluent (POME) [18, 24]. However, another point to note is that all the mechanisms used for the oil extraction from virgin sources studies have also been used in oil recovery process. The authors used the term extraction and oil recovery to describe the recovery and extraction of oil and bioactive compounds. This can be from the virgin source or from the waste. The term recovery in this context described the recovery of residual palm oil and bioactive compounds from oil palm mesocarp fiber, which is a waste product of palm oil mill.

2.1 Methods Use in Residual Oil Recovery

In every palm oil mill industry, mechanical press is used to squeeze out palm oil from the digested mesocarp. A major drawback of the process is that some oil would still remain in the mesocarp even after the pressing. The amount retained was about 5.0% to 8.0% [25] dry basis, and 1.7% to 2.7% wet basis equivalence [11]. Several efforts and inventions were made to recover the residual oil, which are categorised as conventional and biological methods.

2.2 Conventional Process

2.2.1 Mechanical Systems

"Residual Oil Recovery system (RORS)" is a type of mechanical system that has been developed by Subramaniam, Menon, Sin and May [11]. It has the ability to recover the residual oil in the OPMF. The system uses the washing and pressing technique. The extract from the pressing would be directed to the vibrating screen and then to the oil tank or clarification tank. The water generated can then be treated and recycled. The oil recovered by the RORS produced better quality oil than the normal palm oil in terms of caroteenes, vitamin E, free fatty acids (FFA) and deterioration of bleaching index (DOBI) analysis [11, 26].

2.2.2 Dissolved Air Flotation (DAF)

This method removes the free oil from the wastewater. The process clarifies the waste water by removal of oil and other suspended matter. High pressure is used in dissolving the air in the waste water which is done at atmospheric pressure inside the flotation basin. Air released is stick to the oil causing the oil flotation on the surface of the effluent [27]. Finally the oil on top is removed by skimming.

The major limitation of this method in wastewater treatment is that it cannot remove oil encapsulated within the remnant source. For example oil encapsulated within the fibre after extraction cannot be freed by this process. Oil from the sludge of POME may require a manifold round of air dissolved in the waste water. Therefore this method can only be best applied to the free oil. Another limitation of this method is that solid source or sample like OPMF is exempted from DAF since it is not liquid.

2.2.3 Solvent Extraction

Solvent extraction has been used for several decades in the oil extraction from oil seeds. It has also been applied in oil recovery process of oil palm fruits and other palm trees. This method is believed to be the earliest method in oil recovery of palm oil. Solvent extraction is used to recover oil trapped in the PPF after being pressed in the oil mill. The solvents used in this process include, hexane, chloroform, ethanol and CO_2 [13, 28]. The most common solvent is hexane which is a non-polar solvent. Hexane has been used in the extraction of oil from other vegetable seeds, such as rapeseed and soybean. Hexane-based processes have been in commercial operation for a long time. For such methods, it is possible to achieve oil yields in excess of 95% with a solvent recovery in excess of 95% [29]. Extraction by this means require size reduction of the substrate to enable an increase in surface area, making the substrate easily available to the solvent. With the size reduction, the pressing may not be necessary, since the oil and solvents can be leached out by ordinary filtration using mesh. The filtrate can then be channelled to the rotary evaporator where the solvent is removed.

Solvent extraction by the use of hexane can be divided into three major techniques; the cold, reflux and soxhlet extractions. Cold extraction with hexane involves no heat and any sort of agitation; shaking or stirring. This process is also referred to as the conventional hexane extraction which is carried out at room temperature. The other two methods; reflux and soxhlet, involve heating with different theoretical conditions. Soxhlet is carried out with a condensed hexane and reflux with boiled hexane, consequently different amount and quality of extracts are generated. In a comparative analysis of the three methods in palm oil recovery, recovery by soxhlet gave the lowest yield (3.78%), followed by cold extraction (4.35%) and reflux extraction (4.94%). The oil extracted by reflux extraction displayed a darker brown colour compared to the cold and soxhlet methods, [30]. This might be due to the exposure of raw material surface area against contact with the solvent used.

Pressurized liquid extraction (PLE) is another example of soxhlet-hexane extraction method, an extraction procedure that combines high temperature and pressure with liquid solvents to attain fast and efficient extraction of analytes from various matrices. The solvent that is commonly used is the *n*-Hexane, and has been proven as a more suitable organic solvent to be utilized for the extraction. Equivalent recovery of approximately 100 % with soxhlet method is promising with the PLE [17]. The main disadvantages of the conventional reflux and soxhlet extractions are usually; long time of extraction and degradations of target compounds [31, 32].

The supercritical carbon dioxide (SCO_2) is a kind of solvent extraction which involves liquefied carbon dioxide. When CO_2 is held at or above its critical temperature and critical pressure it behaves usually as a gas at standard temperature and pressure (STP), or as a solid called "dry ice" when frozen. Therefore the critical point above the STP is the supercritical state [33]. The fluid adopts properties midway between a gas and a liquid. The supercritical state of CO_2 is an important industrial solvent owing to its role in chemical extraction, its low toxicity and environmental impact. Supercritical CO_2 (SCO_2) has been utilized in the past, as a nontoxic alternative to hexane and other organic solvents for the extraction of oil from seed bearing oil, such as cottonseed, peanut, rapeseed, sun flower and soybean [34-39].

In general, the conventional solvent extraction yields oil with low-quality that requires extensive purification operations; solvent removal, degumming, neutralizing, decoloring, deodorizing [40]. On the other hand alternative deoiling processes, such as pressing which is a mechanical process, are customary and applied for oil seeds containing 20% oil [41]. Finding reveals that SCO_2 allows an almost complete recovery of oil seed (6.5% yield), which is of a greater quality than the oil extracted with hexane (5.0% yield) from a rosehip [28]. Besides the research finding indicating the quantity or the efficiency of the recovery using the supercritical state, interest in the use of hexane has been revived by increasing environmental concern. Organic solvents, particularly hexane can contribute to the emissions of volatile organic compounds (VOCs) [29], the discharge of which is worrisome since the compound can react with another compound to destroy the ozone. Conversely, the CO_2 used in the supercritical process is non-hazardous and non-flammable compared to the flammable petroleum-based solvents, hexane or acetone [42]. SCO_2 extraction has been used in recovering residual oil from palm pressed mesocarp fiber, the process allows for the concentration of minor constituents from the residual oil. Components such as vitamin E, squalene, and carotene were separated in different fractions [25, 42]. In an effort to extract and determine the valuable minor components from palm-pressed fiber, chloroform, hexane and liquid carbon dioxide were used. The results showed the solvents to be nearly better in extracting carotenoids, sterols and vitamin E [13].

The use of SCO_2 also requires high pressure in order to attain liquefaction of the CO_2, making the process highly energy intensive. Even with the toxicity of the conventional hexane extraction, researchers find the conventional hexane more practical for industrial use [43], reason why nearly all oil seeds extractions are carried out by the use of hexane. The solvent extraction of oil from seeds is the most common and efficient extraction technique, both from seeds with oil content < or > 20% and from those with high oil content[44]. Table 1 shows different quantity of residual oil generated from solvents. Most high quantity being generated by hexane.

Table 1 Residual palm oil generated by different solvent

Method	Process	% oil recovered	Reference
Solvent (petroleum ether, hexane)	Extraction at room temperature (28 °C), 200 mL sample of POME was mixed with solvent in a 1:1 ratio. Afterwards mixed in a flocculator at 150 rpm for 10 min.	1710 mg/L (using petroleum ether) and 3280 mg/L (using *n*-hexane). The carotene content in it was about 400 ppm	Ahmad, Chan, Shukor and Mashitah [18]

Method	Process	% oil recovered	Reference
Solvent (hexane, chloroform, & ethanol	Drying of PPF for 1 hour at 50-60 °C followed by extraction in Soxhlet apparatus.	5-6% Residual on dry basis contains carotenoids (4000-6000 ppm), vitamin E (2400-3500 ppm), and sterols (4500-8500 ppm).	Choo, Yap, Ooi, Ma, Goh and Ong [13]
Solvent (Hexane)	The dried PPF fibre 0.4 – 0.6 mm mesh were subjected to cold extraction, soxhlet & reflux in 1 L hexane for eight hours.	3.78%, 4.35%, 4.94% residual oils from soxhlet, cold and reflux extractions respectively	Neoh, Thang, Zain and Junaidi [30]
Pressurized liquid extraction (PLE)/ Solvent (*n*-hexane and chloroform)	5 g dried PPF (60–70 °C for 1 h) was used for extraction using 100% *n*-hexane inside home-made accelerated solvent extractor. The same sample was used for chloroform inside a Soxhlet apparatus for 8 h.	3.7–4.0 mg /ml of Vitamin E isomers and β-carotene of 3.3–3.5 mg/ ml (using PLE). Vitamin E isomers present in residue oil are a -tocopherol (55.2%), γ-tocotrienol (24.9%), a-tocotrienol (17.2%) & δ-tocotrienol (2.8%) (using *n*-hexane as an extraction solvent)	Lau, Choo, Ma and Chuah [42]

3.0 BIOLOGICAL PROCESS

3.1 Enzymatic Treatment

Industrial processes for the recovery of edible oil from oil seeds generally involve the use of solvents or mechanical processing [45, 46], but, high energy dispensation, purity and environmental concern have motivated the search for alternative methods and better solvent. In extracting palm oil from oil palm mesocarp, the aqueous extraction has been in use [47, 48], however low oil recovery is a major challenge for aqueous extraction process (AEP) [46, 49]. This drawback can be improved by the application of hydrolytic enzymes [46, 50, 51]. The hydrolytic enzymes that disintegrate the structural polysaccharides forming in the cell wall of oilseeds, or one that hydrolyze the proteins which form the cell and lipid body membranes [29, 52]. Considering the nature of the cell walls mainly composed of cellulose, connected with hemicelluloses, pectin substances and lignin. These structures could also be broken by means of enzymes, to achieve a significant improvement in extraction yields [53, 54]. Since enzyme cannot react ordinarily or alone, it therefore needs an interface to act, the best of which is water, the application of the hydrolytic enzymes brings about the aqueous enzymatic process.

The enzyme as a very fragile biological molecule has to be in an aqueous system to stabilize its physiological requirements. Enzymes such as cellulase can be more effective since they can break down the complex polysaccharide building of the fiber [51]. Teixeira, Macedo, Macedo, da Silva and Rodrigues [55] carried out an extraction of palm oil from mesocarp fiber using aqueous enzymatic treatment and found to be more effective than the aqueous process alone [55]. To evaluate the performance of the enzymes in the recovery of palm oil, tannase and the other enzyme blends were tested: pectinase/ cellulase, pectinase/ cellulase /tannase, and tannase alone. The result indicated; pectinase/tannase/cellulase and pectinase/cellulase yielded a recovery of approximately 90% [55]. This indicates that single enzyme system alone may not be effective in bringing an efficient recovery of oil. It has also demonstrated that enzyme such as cellulase and pectinase can play a major role in palm oil recovery. This also supports the fact that the cell wall of plants composed of cellulose, hemicellulose, pectin and lignin [54], a reason why enzyme combinations with pectinase was highly effective. A study by Sharma and Sharma [56], also revealed similar findings, however, without tannase and stressed that even at higher enzymes concentrations individual enzymes underperformed when compared with the enzyme mixture in olive oil recovery. Enzyme formulations not only degrade the walls of oil bearing cells, but also break the colloidal system in oil paste. In that way they release maximum oil and also improve the oil quality [57]. The trapped oil released is enriched with other valuable phytochemicals such as antioxidants, vitamin E and taste-flavor compounds as a result of the degradation of cell walls [58].

Oils from industrial effluents like POME can also be recovered by hydrolytic enzymes. Oil encapsulated within the sludge can be dislodged by this method. The encapsulated oil within the sludge is normally found inside the fibre debris which is linked to proteins and other organic compounds like cellulose, hemicellulose, pectin and starch. To get the oil out or to increase the permeability of the oil away from the cell membrane, the cell wall has to be degraded. This can be achieved by the use of similar enzymes as discussed above. This process will enhance the release of oil globules and other coalescence. Therefore, for an achievable use of hydrolytic enzymes in residual oil recovery, enzyme mixture is highly required. This could aid bioconversion of some of the organic compounds within the fibre. Compound such as cellulose and hemicellulose can be converted to value added products like glucose and xylose. The use of the enzyme in palm oil recovery is highly effective but the cost of the enzymes is the major drawback considering the quantity of the oil to be realised from the process. If the enzymes were to be produced, the cost of purification is also troublesome.

3.2 Microbial Treatment in Residual Palm Oil Recovery

3.2.1 The Use of Indigenous Microbes in a Solid State

The direct microbial involvement in residual oil recovery was not reported in Malaysia or Asia at large. In African countries like Nigeria, such a process was reported [59]. The reason is attributed to the higher rate of oil loss. The palm oil extraction is carried out predominantly by small scale producers, which account to about 80% of the oil palm sector and uses rudimentary equipment for processing, while the formers accounts for about 20% [60] . This rudimentary approach result to about 25 % loss of CPO [61, 62].

The method applied to recover the residual oil or what is called the "second grade oil" or "technical grade oil" from palm press fiber involves the addition of POME to the fiber for 2 to 4 days in a solid state process [60, 63, 64], this allows fermentation to take place and subsequent recovery of the oil. However, the mechanism of leaching out of oil from PPF by this means was not clearly reported. The residual oil from this source is a low quality oil due to high levels of free fatty acid, impurities, peroxide and moisture content [65, 66]. The high fatty acid content can be associated with the activity of lypolytic enzymes present in the palm fruit mesocarp [65, 67-69], which by venture the fiber debris could also pass to the effluents as POME or remain therein in the mesocarp fiber.

From a biological viewpoint, fermentation is able to take place and proceed due to the activities of microorganisms. Numerous lipolytic microorganisms have been found in POME including the phosphate-solubilizing, cellulolytic and nitrifying bacteria [70, 71]. Several fungi with lignocellulose degrading activities were also reported and isolated from pressed mesocarp fiber. Most of those strains possess fermentative ability [72]. The use of POME as an additive to the palm pressed fiber in order to recover the oil can be attributed to the fact that POME has more indigenous lignocellulosic degrading microbes than the Palm pressed fiber. In that case, the degradation of the mesocarp fiber will proceed rapidly. However, the exact quantification of the oil recovered cannot be ascertained as the additive (POME) has oil as well. Secondly, the purity of the oil recovered is also questionable as POME has an oil content with odour and foul smell, presumably the actual content has been changed due to the lot of microbial activities. Thirdly, the role of the microbial community therein may not be understood, as the microbial community reported from pressed mesocarp fiber may not be necessarily present in POME, vice versa. Kinetics, assay and other physiological data of the microorganism may also be missing. Therefore, a better recovery can be attained if known strains are to be used without the addition of any foul effluent to keep the quality of the oil recovered pure.

3.3 Solid State Fermentation for Residual Palm Oil Recovery

Fermentation processes can be divided into two systems, submerged fermentation (SmF) and solid state fermentation (SSF). SmF is based on microorganism cultivation in a liquid medium containing nutrients. As for SSF, it can be defined simply as any fermentation process allowing the growth of micro-organisms on moist solid materials in the absence or near absence of free-flowing water [73]. The materials used in SSF can be categorised into two categories: the synthetic materials also called the inert and the organic material also known as the non-inert. The former only acts as an attachment place while the latter functions as a source of nutrient raising the term support-substrates. The utilization of support-substrates provides some nutrients to the micro-organisms. Biological or agricultural wastes such as lignocellulosics are a first-class exemplar of this kind of material.

Traditionally, SSF was used for producing fermented products (foods) such as dairy products, tempeh, soya sauce and fermented sorghum. But, nowadays biotechnological advances have opened ways for diverse industrial and biotechnological interactions processes, ranging from pretreatment, bio-detoxification, enzyme production and enzymatic saccharification [74-77]. The oil palm mesocarp fiber as a solid lignocellulose biomass has also been delignified by the SSF to produce reducing sugar by white rot fungus [77]. In modern times, SSF has received more attention from researchers since several studies have demonstrated that the process lead to higher yields and productivities or better product characteristics. By the use of low cost agricultural and agroindustrial residues as substrates, capital as well as the operating costs is lowered. Recovery of the residual oil from solid substrate can proceed better in the solid state than the submerged state, as the former is known to give; higher concentration of products, high volumetric productivity, a lesser amount of effluent generation, and also requires only a simple fermentation equipment [78]. The less water volume in SSF has also a large impact on the cost-cutting measure of the process mainly due to smaller fermenter-size, reduce stirring and lower sterilization costs and finally reduced downstream processing, [79-82]. The main drawback of this type of cultivation concerns the scaling-up of the process, largely due to heat transfer and culture homogeneity problems [83, 84]. However, research interest has been directed towards the development of bioreactors that overcome these difficulties [84, 85]. This and other development led to more growing interest in the application of SSF.

Undoubtedly, biological processes are more eco-friendly than chemical processes. Microbial treatment of lignocellulosics has the advantages of a low-energy demand, less waste production and lack of environmental effects [86]. Thus, recovery of palm oil by such a process will be a better technique. The OPMF is a lignocellulosic material comprising cellulose, followed by hemicellulose and lignin [87]. Cellulose and hemicellulose are macromolecules synthesized from different sugars; whereas lignin is an aromatic polymer constructed from phenylpropanoid precursors [88]. The two former are entrapped by the lignin, which is a more complex polymer. For the biological process of palm oil recovery to be achieved this structure must be degraded. The organisms primarily responsible for lignocelluloses degradation are fungi. By the delignification and subsequent breakdown of other polysaccharides the oil entrapped within the biomass is set free. A simple description of palm oil entrapped and dislodged from the oil palm fibre lignocelluloses is seen in Figure 2.

Out of the lignocellulosic degrading fungi, the most rapid degraders are basidiomycetes [89-91]. The most widely studied white-rot fungi is *Phanerochaete chrysosporium*, which is one of the holobasidiomycetes. *Trichoderma reesei* and its mutants are the most widely studied ascomycete fungi, and is used for the commercial production of hemicellulases and cellulases [92-94].

3.3.1 Potential Fungi Strains for Palm Oil Recovery

The choice of the microorganism to be used in SSF depends on the desired end product. Among the microbial communities, fungi are considered to be the best degraders. Due to the low moisture content in the fermentation media, fungi are the most suitable microorganisms for SSF. The ability of fungi to grow on, and produce extracellular enzymes in order to degrade lignocellulosics biomass is mediated by their ability to produce two types of extracellular enzymatic systems. The hydrolytic system, which produce hydrolase that are responsible for polysaccharide degradation and a unique oxidative and extracellular ligninolytic system, which degrades lignin and opens phenyl rings. These complex sugars upon degradation serve as a source of nutrient [81], particularly carbon for growth and energy derivation by breaking the chemical bonds and transferring electrons to and fro their central metabolic pathways. As the fungi is consuming the nutrients and breaking down the lignocellulose structure oil entrapped is dislodged as shown in Figure 2.

In palm oil recovery, enzymes such as lignolytic, cellulases, xylanases, and pectinase are highly important considering the nature of the oil palm mesocarp fiber, being a lignocellulosics material. Lignolytic are of utmost among these arrays, because the accessibility to the remaining polymers depends on the lignin degrading potential of the fungi. Lignin presence in plant cell wall is to provide structural support, resistance against; microbial attack, permeability and oxidative stress [88]. Even though it is recalcitrant for attack by most microorganisms, quite a number of fungi mostly basidiomycetes whit rot are able to degrade the polymer effectually [89-91]. Table 2 shows some lignin degrading fungi mostly belonging to the group basidiomycota with the exception of the trichodermas. *Panerochaete chrysosporium* strains concurrently degrade cellulose, hemicellulose and lignin; whereas fungi like *Ceriporiopsis subvermispora* selectively remove lignin in advance of cellulose and hemicellulose [88]. These fungi are mostly basidiomycetes used in different condition mostly SSF. Besides lignolytic fungi, a combination of other activities such as cellulases, pectinase and xylanases are desirable since we have previously seen the significance of cellulase, pectinase in oil recovery under aqueous enzymatic process. A reason attributed to the nature of the plant cell wall cell wall having a collection of cellulose, hemicellulose, pectin and lignin.

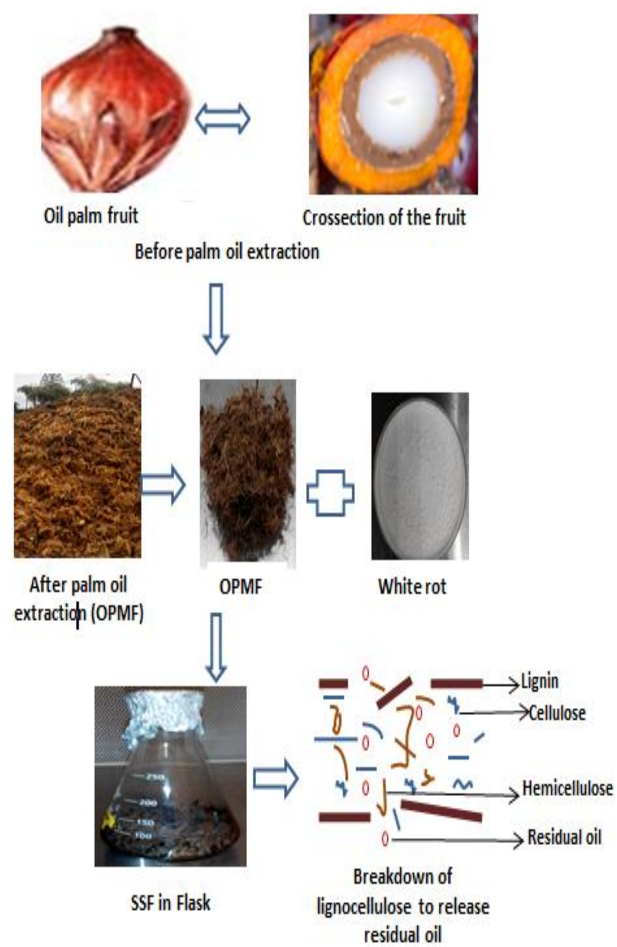


Figure 2 Proposed schematic diagram of residual Palm oil recovery from Oil palm mesocarp fiber in SSF

The degrading potential of the microorganisms should not be a singular parameter for choosing the particular strain to be employed in the recovery. The point is that microorganisms with high lypolitic activity may not lead to a successful process. This is because the attention of the microbes can be attracted away from lignocelluloses enzyme secretion to lipases secretion due to the presence of the oil bodies which acts as lipase inducers [95]. The secretion of lipase would result in high fatty acid production. The high amount of free fatty acids turns the oil unfit for human consumption without suitable refining [68]. Therefore, any additional refining to the normal refining process is an additional cost, a process that must be avoided.

Table 2 SSF Processes with different potential lignocelluloses degrading fungi

SSF Process	Strains	References
Lignocellulose degradation mechanism	*Phanerochaete chrysosporium* and *leurotus ostreatus*	Kerem, Friesem and Hadar [96]
Bioremediation	*Phanerochaete chrysosporium* and *Coriolus versicolor; Anthracophyllum discolor, Lenzites betulina* (Ru-30) and *Galerina patago´nica* (Sp3),	[Nigam, Armour, Banat, Singh and Marchant [97], Tortella, Rubilar, Gianfreda, Valenzuela and Diez [98]]
Lignocellulolytic enzyme production	*Phanerochaete chrysosporium; Phlebia radiate; Anthracophyllum discolor* Sp4; *Trametes Trogii; Funalia trogii IBB 146, Lentinus edodes IBB 363, Pleurotus dryinus IBB 903, and P. tuberregium IBB 624); Trametes trogii;* Stereum hirsutum (Sp1) Trametes versicolor (Ru-0030) & Lenzites betulina (Ru-30)	Fujian, Hongzhang and Zuohu [99], Vares, Kalsi and Hatakka [100], Acevedo, Pizzul, Castillo, Rubilar, Lienqueo, Tortella and Diez [101] [Patrick, Mtui, Mshandete and Kivaisi [102], Kachlishvili, Penninckx, Tsiklauri and Elisashvili [103], Levin, Herrmann and Papinutti [104]] Tortella, Rubilar, Gianfreda, Valenzuela and Diez [98]
Ethanol production/ pretreatment	*Phanerochaete chrysosporium*	Shi, Chinn and Sharma-Shivappa [86]
Cellulases production	*Trichoderma reesei QMY-1. Trichoderma reesei QM9414 and T. reesei MCG77, mutants. Trichoderma reesei ZU-02*	[Chahal [105], Latifian, Hamidi-Esfahani and Barzegar [106]],Xia and Cen [107]
Biopulping	*Ceriporiopsis subvermispora*	de Souza-Cruz, Freer, Siika-Aho and Ferraz [108]
Fiber extraction	*Ganoderma lucidum*	Hariharan and Nambisan [109]

4.0 ENVIRONMENTAL ASPECT OF THE RESIDUAL OIL RECOVERY PRACTICE

A great environmental concerned as a result of the human actions due to development activities has increased recently. Government and private sectors including Palm oil industry have been urged to begin all development projects within the concept of sustainable development. Sustainable development should be the backdrop of almost all planning proposal, in order to foresee the impact of the proposed development to the environment. Improper handling of any resource can pollute the soil, water and air, in general the production industry.

The growing challenge for palm oil production industry is to find ways to increase production yields and improve their waste management while putting cognizance need for the nutrient recovery. The efficiency and the development of new advances for the waste management and recycling in industries are usually weighed against yardstick. These yardsticks are the developed framework for the sustainable development of the oil palm industry [110]. As part of the Best Development Practices (BDPs), the framework policies on BDPs now require palm oil industries and their plantations to look into protection of the physical environment as well as maintaining the biological environment such as biodiversity, high yielding planting materials and reduced weeds, pests and diseases. This is geared trend towards becoming an environment-friendly industry a “zero waste” concept that is now being pursued as an environmental goal for this industrial sector. Which is cantered on complete recycling and/utilisation of all perceived waste components and by-products generated by the oil palm industry, from the plantation to the milling operations. Table 3 shows some environmental issues and their characteristics effect. Oil palm biomasses like OPMF is also captured among waste to be properly addressed in terms of environmental issues.

Table 3 Environmental issues of Palm oil industry [111]

S/N0	The environmental issues	Characteristics Effects
1	Water pollution attributable to indiscriminate discharge of non-treated or partially treated palm oil mill effluents into public waterways.	Depletion of dissolved oxygen level of the river and ultimately destruction of aquatic life and deterioration in the riverine eco-system.
2	Poor interim storage of solid waste materials including boiler and incinerator ash and their raw materials. Others are the spent bleaching earth, and sludge separator residue	Public nuisance due to dark smoke emission containing soot and partially carbonised ferrous particulates. Easy accessibility of these materials to effluent and storm water drainage systems, especially in open areas expose to rain and eventually causing contamination. Significantly increase the cost of effluent treatment.
3	Improper land-application techniques or practices for solid and/or liquid wastes; application of POME to the plantation and the use of EFB for mulching etc.	If poorly controlled resulting to; Groundwater contamination. Surface water pollution due to excessive application and run-off into watercourses; Washout into watercourses due to heavy rainfall; Odour and fly nuisances. Breeding grounds of rodents and other vectors.
4	Air pollution due to the use of solid fuel fired boilers, this includes the application of OPMF as boiler fuel and the incineration of empty bunches.	Potential to cause localised problems of air pollution, especially if the palm oil mill is located in close proximity to residential areas.
5	Odour emanation from poorly managed effluent treatment ponds; this is more often, if they are located in close proximity to neighbouring residential areas.	-
6	Some noise from the milling processes; noise is usually a much lesser external environmental concern. Noise levels are typically within acceptable limits at the palm oil mill boundary fencing.	-

As part of the pollution control and cleaner production strategy, vital consideration is directed towards process innovations that can be incorporated into existing production lines in order to minimise or prevent waste generation at source. In general, palm oil mills can accomplish significant progress through adoption of residual oil recovery as one of its waste management/control measures. This will immensely pedal the sector to a cleaner production with the following benefits; minimisation of waste generation at source through in-plant control and housekeeping measures, resource recovery and utilisation, recycling of water and waste constituents and cost-effective improvements of end-of-pipe solutions (if incorporated into its existing production path).

5.0 ECONOMIC VIEWPOINT OF RESIDUAL PALM OIL RECOVERY

The mesocarp fiber generated from palm oil industry contained residual oil, which is about 5.0 - 8.0 % of the mainstream palm oil [25]. Analysis of such discharged in Malaysia is around 5.0-11.0% [12]. This value translates into oil loss/ tonne FBB in range of 0.25-55%. In 2011 alone, 94.55 million tonnes of FFB were processed. This value translate into 18.91 million tonnes of CPO produced [112]. The oil loss from pressed mesocarp fiber per tonne produced was in a range of 236 375t - 520 025t CPO amounting to the loss of about RM 700 million-1.5 billion nationally, at a CPO price of RM 3000 [11].

Extracts from oil palm mesocarp fiber (or palm fruit mesocarp fibre) contain sterols, carotenoids, tocopherols and tocotrienols as well as phenolic compounds which serve as antioxidants in the body when used as supplements in food [13, 30]. These compounds can be good nutrient supplements. Carotenoids has drawn greater attention than before, mainly due to the benefits to health, as a nutritional supplements [113], as coloring agents for food and pharmaceutical industries, as well as cosmeceuticals additive [114-116]. Beta-carotene represents the largest product market supported by those extensive used.

The international herbal market for nutraceuticals and phytomedicines reached USD 70 billion, with an typical annual growth rate of 15 % [19, 117], estimation of that of carotenoid indicated $1.2 billion in 2010, with a compound annual growth rate (CAGR) of 2.3%, to reach $1.4 billion by 2018 [118]. The world carotenoid market is shown in the Table 4. The table includes the current monetary value by UBIC research consulting.

Table 4 World carotenoids markets [116]

Sections	2015 Up date (€)	Malaysian (RM)
All sections	2,390	11,166.25
Market Analysis	1,690	7,895.80
The World Carotenoids Market	890	4, 158.14
The World Beta-carotene Market	570	2,663.08
The World Coloring Agent Market	250	1,168.02
Suppliers	700	-

Tocopherols and tocotrienols are two classical components of Vitamin E. Each class has four distinct compounds. Most attentions on Vitamin E have been focused on the alpha and gamma tocopherols. This is because it can easily be isolated and synthesized. A reason for commonly use in supplementation. Research on the tocotrienols is increasing for their significance in maintaining good health. For example, research findings indicated that tocotrienols can clear atherosclerotic obstruction in the carotid artery, a condition that can lead to stroke [119].

Natural vitamin E market has been experiencing a major imbalance in supply and demand from the past few years as the prices of natural vitamin E have faced a substantial increase. The reasons include; the supply shortage of the primary raw material, deodorized distillates, that goes into manufacturing natural vitamin E. Stakeholders in the natural vitamin E are in the process of studying alternative means of production that could equalize the supply-demand imbalance [120]. The Global volume consumption (GVC) of natural source vitamin was estimated at 10.3 thousand metric tons, 2012; 10.9 thousand metric tons, 2013; and projected to be 18.1 thousand metric tons in 2020, thus exhibiting a CAGR of 7.3 % between 2012 and 2020. [120].Vitamin E from oil palm mesocarp fiber oil can be a novel source of supply considering its nutritional value as a source of tocopherols and tocotrienols, carotenoid and the volume lost per annum.

6.0 CONCLUSION

The underlying principles of waste management are to minimise its generation and recycle the waste. The agro-industrial wastes such as palm oil residues are not exceptions because of the economically useful alternative. For that to be achieved, it required the exploration of its potential benefit which will allow for the indigenous energy sources and the recovery of energy in the palm oil industry. The renewable energy sources of the industries should go beyond the primary (direct) application as a power, several possible methods can be used to derive other retained sources of the energy, which can act as a secondary source (after bio conversion), and still be used in a primary way thereafter. Residual oil recovery by means of microbial fungi in a solid state condition is therefore a better option prior to direct application or conversions to other products.

Acknowledgement

This work was supported by Ministry of Higher Education Malaysia and Universiti Teknologi Malaysia under the grant number 14H42 (RUG of UTM).

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