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A Review of Palm Oil Mill Effluent (Pome) Water Treatment

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Abstract: Palm oil is one of the two most important vegetable oils in the world's oil and fats market. The extraction and purification processes generate different kinds of waste generally known as palm oil mill effluent (POME). The environmental impact of POME cannot be over emphasized; hence the need for treatment measures to reduce these impacts before discharge. Therefore, this paper reviews the processing, purification of palm oil and the different methods of treatment applied to the POME that is being generated. Various methods such as tank digestion and facultative ponds; tank digestion and mechanical aeration; decanter and facultative ponds; anaerobic digestion and facultative ponds and so on, were reviewed, each with its merits and demerits in application. The adsorption treatment of POME using boiler fly ash is also being applied. Therefore, the treatment of POME is inevitable if a friendly and healthy environment devoid of pollution is to be met and also to meet-up with increasingly stringent environmental regulations. Prospective treatment methods for POME were also reviewed. Moreover, the effective treatment of POME yields useful products such as methane, biodegradable plastic, fertilizers and animal feeds.

Key words: POME · Palm-oil · Effluent-water · Pollution · Environment

INTRODUCTION

Palm oil is one of the two most important vegetable oils in the world's oil and fats market following Soya beans [1]. Oil palm (*Elaeis guineensis*) is the most productive oil producing plant in the world, with one hectare of oil palm producing between 10 and 35 tonnes of fresh fruit bunch (FFB) per year [1, 2]. The palm has a life of over 200 years, but the economic life is 20-25 years (nursery 11-15 months, first harvest is 32-38 months from planting and peak yield is 5-10 years from planting).

Usually, the harvested part is the fruit "fruit bunch" whereby oil is obtained from the fleshy mesocarp of the fruit. Oil extraction from flesh amounts to at least 45-46% while kernel accounts for at least 40-50%. The palm has a highly varied nutrient demand which depends mainly on the yield potential determined by the genetic make-up of the planting material and on yield limit set by climatic factors such as water, effective sunshine and temperature.

Crude palm oil contains fatty acid ester of glycerol commonly referred to as triglycerides, therefore, contributing to the worlds need of edible oil and fats. It is composed of approximately 50% saturated fats (primarily palmitic acid) and 40% unsaturated fats (principally linolenic and oleic acid); a unique composition if compared with other major fats [3]. The distinctive colour of the oil is due to the fat soluble carotenoids (pigment) which are also responsible for its vitamins E (tocopherols and tocotrienols) content. There are several stages of processing the extraction of palm oil from fresh fruit bunches. These include sterilization, bunch stripping, digestion, oil extraction and finally clarification and purifications; each process with its own various unit operations [3].

These extraction and purification processes generate different kinds of waste.

Extraction of crude palm oil: As mentioned earlier, there exists several processing stages in the extraction of crude palm oil from fresh fruit bunches. The first stage is sterilization. This involves subjecting freshly harvested fruit bunches brought to the mill to a high pressure steam (120 to 140°C at 40psi) with a minimal delay so as to inactivate the lipolytic enzymes that causes oil hydrolysis and fruit deterioration. The next stage is called bunch stripping. This offers a means of separating the fruits from the bunch stalks by mechanical stripping. The separated and sterilized fruits thereafter undergo a process of

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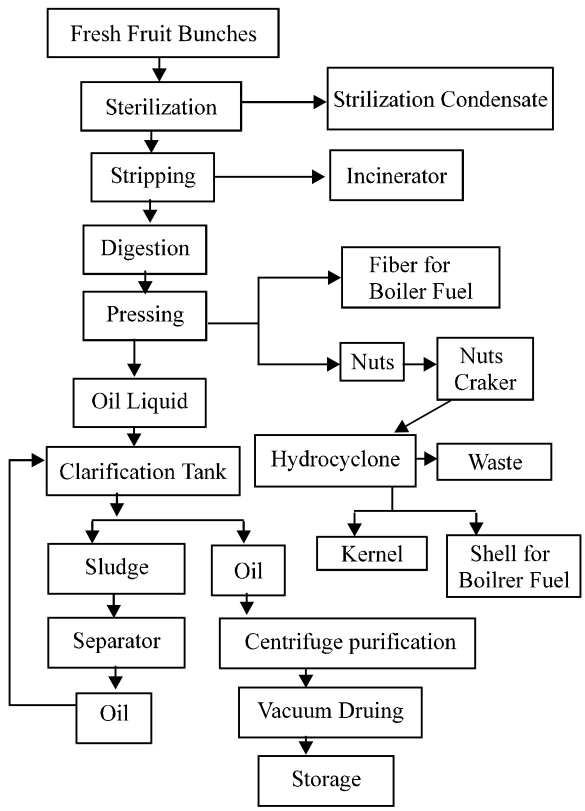

Fig. 1: A block flow diagram of the palm oil mill process.

digestion. This is achieved by reheating the fruits using steam to a temperature of 80-90°C. This prepares the fruits for oil extraction by rupturing the oil bearing cells in the mesocarp and loosening the mesocarp from the nuts. Oil extraction followed by clarification and purification are the last processes of oil extraction. The crude oil is extracted from the digested fruit mash by the use of the screw press without kernel breakage [4]. This palm oil production process is shown on Fig. 1.

The extracted liquid and nuts are discharged from the screw press. However, the extracted oil contains varying amounts of water, solids and dissolved impurities that must be removed. The fiber particles from the pressed crude oil are first removed by passing the oil over a vibrating screen; sand and dirt are allowed to settle. Water is removed by settling or centrifuging and finally by vacuum drying. It is worthy to note that the moisture content of the clarified crude oil is still about 0.1-0.25% of moisture [4]. This helps in maintaining oxidative stability and also prevents the deposition of small amounts of soluble solids known as gums. The final product is consumed locally as crude palm oil or can further be refined.

Oil palm waste products: The oil palm mills generate many by-products and wastes beside the liquid wastes that have been mentioned, that may have a significant impact on the environment if they are not properly dealt with. The most common among these by-products is the empty fruit bunch. The empty bunch is a solid waste product of the oil palm milling process and has a high moisture content of approximately 55-65% and high silica content, from 25% of the total palm fruit bunch [5]. The treated empty bunches are mechanically crushed (de-watered and de-oiled) in the process, but are rich in major nutrients and contained reasonable amounts of trace elements. They have a value when returned to the field to be applied as mulch for the enrichment of soil [6]. However, it was noted that over application of the effluent must be avoided as it may result in anaerobic conditions in the soil by formation of an impervious coat of organic matter on the soil surface [5,7].

Air emission from the oil palm mills are from the boilers and incinerators and are mainly gases with particulates such as tar and soot droplets of 20-100 microns and a dust load of about 3000 to 4000 mg/nm. Incomplete combustion of the boiler and incinerator produce dark smoke resulting from burning a mixture of solid waste fuels such as shell, fiber and some times empty bunches. These boiler fly ashes are also a waste in them and also pose problems of disposal. In the bid to achieve a zero discharge of the palm oil mill, boiler fly ash have been used to reduce the BOD, TSS, colour and other contaminants from POME before discharge [8, 9]. Boiler fly ash has also been used in the removal of heavy metals from other industrial effluents [10-14].

Palm oil mill effluent (POME): Effluent water is defined as water discharged from industry, which contains soluble materials that are injurious to the environment. Such soluble materials may be gases such as CH_4, $S0_2$, NH_3, halogens or soluble liquids or solids which contain ions of either organic or inorganic origin and with their concentration above the threshold value [15]. Since these compounds are harmful to the environment, it becomes necessary that effluents water should be treated or purified before discharged into the environment. Thus, the major objective of industrial effluents treatment is to reduce the amount of these potentially toxic compounds to their acceptable threshold limit value (TLV), according to some standards of the Federal Environmental Protection Agency (FEPA); World Health Organization (WHO); Department of Petroleum Resources (DPR); etc.

Generally, the characteristics of industrial effluents are given as follows:

- Soluble organics resulting in dissolved oxygen depletion in streams and estuaries and/or causing taste and odour.
- Organic suspended solids resulting in dissolved oxygen depletion.
- Inert suspended solids causing turbidity and resulting in bottom sediments.
- Toxic substances and heavy metals.
- Oil and floating materials.
- Dissolved salts particularly phosphates, chlorides and nitrates [16].

Specifically, palm oil mill effluent (POME), is a general phrase referring to the effluent from the final stages of palm oil production in the mill. It includes various liquids, dirties, residual oil and suspended solids. POME in its untreated form is a very high strength waste, depending on the operation of the process, that is; informal, semi-formal and formal processes, the biological oxygen demand (BOD) of these wastes ranges from 25000 to 35000 mg/L. It contains about 94% water. POME actually is the sum total of liquid waste which cannot be easily or immediately reprocessed for extraction of useful products and is run down the mill internal drain system to the so called effluent (or sludge) pit.

POME is generated from various points during processing in an oil mill. These include;

- Clarification sludge
- Sterilization condensates
- Fruit washing water
- Hydro cyclone drain-off.
- Various boiler blows down, tank and decanters drain.

The composition of the effluent from these various sources, are mainly water, oil, solids (suspended and dissolved) and sand. Adapalm effluent hand book [17], gave the following composition as percentage of total sludge;

Water	:	93 – 95%
Solid	:	3 – 4%
Oil	:	0.5 – 2%

Also, Sutanto [18], reported the following composition from analysis of typical sample from Malaysia;

Water	: 95%
Oil (free)	: 1.0%
Suspended solids	: 2.0%
Dissolved solids	: 2.0%

The treatment of palm oil mill effluent in Nigeria came up as a result of the harmful effects of the effluent on the environment. Also, the cost cutting measures in all unit operations of a company have been imperative to ensure profit and for survival. The lost revenue in forms of oil loss, water not recycled has necessitated the urge to assess a more economical method of running a palm oil clarification plant [2] and utilizing the effluent water or converting it to other useful products [19,20] and possibly making the water less acidic [16].

Regulatory standards for palm oil mill effluent: The Malaysian experience in effluent control in the palm oil industry demonstrates that a set of well designed environmental policies can be very effective in controlling industrial pollution in a developing country. The Malaysian government's effort to reduce the effluent from the palm oil industry has been implemented through a licensing system, which mainly consists of effluent standards and effluent charges. Progressively, stringent effluent standards were stated in a government environmental quality regulation and were implemented in four stages [21]. Specifically after being given one year to install treatment facilities, palm oil mills were required to reduce their waste water discharges, taking biological oxygen demand (BOD) concentration as the key parameter from 25000 mg/L untreated effluent to 5000 mg/L and to (100 mg/L by 1984 on wards) [21].

In addition to the standards, effluent charges are levied on the biological oxygen demand load discharge. Palm oil mills were given one year (1978) of paying a low fee for the biological oxygen demand load exceeding a standard of 5000 mg/L in recognition of the initial difficulties the industry would face. A more stringent biological oxygen demand standard (100 mg/L in 1984 on word) and hence, higher effluent charges were imposed after that.

The results of policy implementation are very encouraging. The palm oil industry made steady progress towards meeting the target of 100mg/L biological oxygen

Table 1: Industrial Pollution Control Standards for Palm Oil Mills

Parameter	1978	1979	1980	1981	1982	1984	1989
BOD standards Myll	5000	2000	1000	500	250	100	100
No of Mills	131	140	147	157	167	186	254
CPO Production (10^3tons)	1786	2188	2573	2822	3511	3715	6057
BOD generated (tons/ day)	563	690	850	1000	1100	1640	1693
BOD load discharged (ons/day)	563	222	130	58	35	4	5
% reduction in BOD load	0	67.8	84.7	94.2	96.8	99.8	99.7

Source: Markandya and Shibli, 1995.

demand. A progressive reduction in the total biological oxygen demand load discharge was recorded (Table 1). For example, between 1998 and 1989 despite a 93% increase in the number of palm oil mills and a jump of crude palm oil (CPO) production from 1.8 million tons to 6.1 million tons, the daily biological oxygen demand load released to public water bodies fell steadily from 563 tons/day in 1978, to 58 tons/day in 1981 and to only 5 tons/day in 1989. Studies also show that these policies did not result in loss of competitiveness for the palm oil industry.

Palm oil mill effluent management: Effluent management involves the typical handling of liquid waste. The mechanical technique often involves sedimentation, filtration and decolorization of effluent. Mechanical technique is normally at the first stage of purification process to remove suspended solid particles. This is called primary treatment. The commonly used devices include sieve, sedimentation bed and filter. Physico-chemical technique involves coagulation of finely dispersed and suspended solid particles, adsorption of the dissolved impurities such as heavy metals [22-29], selective crystallization, reverse osmosis and ion-exchange processes [30]. Reverse osmosis is most often used at the final stage of effluent treatment.

Secondary treatment is biological process following primary treatment. The forms of secondary biological process include activated sludge, tricking filters, contact stabilization, etc. There are widely known methods of effluent treatment in palm oil mill industries [30].
These include the following:

1. Tank digestion and facultative ponds: In this system, raw effluent after oil trapping is pumped to a closed tank which has a retention time of about twenty days. The liquid is mixed by means of horizontal stirrers. The methane gas (CH_4) generated is flared off into the atmosphere, but the flaring of the CH_4 is unacceptable and calls for improvement on this method. Digested liquid is discharged into a holding pond before it is disposed on land [31].

2. Tank digestion and mechanical aeration: This group consists of cooling/acidification ponds, an anaerobic digestion tank and an aeration pond. Raw effluent after oil trapping is pumped to the acidification pond through a cooling tower and retained for one to two days. It is then mixed with an equal volume of liquid from the anaerobic digester before it is fed back to the digester and the achievement recorded indicates that the effluent water has been treated. The hydraulic retention time of the digester is about twenty days. The digested liquid is discharged to an aeration pond with two floating aerators. The liquid is aerated for twenty days before it is discharged [32].

3. Decanter and facultative ponds: In a few mills, decanters are used to separate the fruits juice after pressing into liquid and solid phase, the liquid which is mainly oil is fed to the conventional clarification process. The water resulting from the clarification station is recycled. The solid is either disposed off on land or is dried in a rotary drier to about 10% moisture and then used as fuel. Thus, the effluent which consists of only the sterilizer condensate and waste from the hydro cyclone is greatly reduced in volume and is treated in a series of ponds [33].

4. Anaerobic and facultative ponds: This system consists of a series of ponds connected in series for different purposes. The effluent after oil trapping is retained in an acidification buffering pond for about two or three days, the resulting effluent is then treated in an anaerobic pond with a hydraulic retention time of thirty to eighty days depending on the mills. This digested liquid is further treated in a series of facultative ponds before it is discharged. In some cases, part of the digested liquid is recycled to the acidification and buffering pond. The total hydraulic retention time of the system ranges from 75 to 120 days [34].

5. Antra system: The treatment consists of a combination of mechanical chemical process and ponds [35]. The raw effluent after oil trapping is separated into water and solid phases using a three- phase decanter. The oil is returned to the main line while the solid is dried in a rotary drier after the filter press. The water containing dissolved and suspended solids is treated with coagulants and flocculants to remove as much solids as possible before

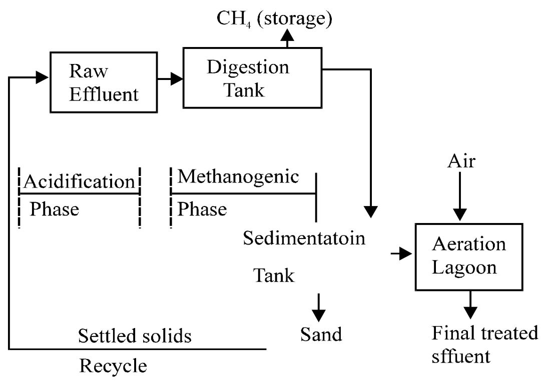

Fig. 2: Flow chart for process treatment of the effluent water

it is fed to an anaerobic digester which has a hydraulic retention time of about ten days. The digested liquid is further treated in an aeration tower and then oxidized [35].

Process treatment of the effluent water: Figure 2 shows the flow chart for the treatment of the effluent water showing the different stages. This is divided into the acidic, methanogenic and aerobic phases.

(a) Acidic phase: This is the first phase of the anaerobic digestion process. It is a very rapid process whereby acid bacteria converts the organic components of the waste into volatile fatty acids (VFA) which in turn acts as substrate for the next phase of the anaerobic process. The pH of the system is depressed during VFA formation [36].

The phase is not susceptible to environmental influence in that changes in environmental conditions like temperature do not affect its required performance, so open ponds are suitable and cost effective. At the start, anaerobic liquid is run down to the pond and then mixed with clarification waste and then pumped over cooling tower in the ratio of 1:1 to 1.5:1. The mixture is left overnight to react. Recycling of anaerobic liquid helps to supply seed bacteria for continuous acidification, cools hot effluent and improves the pH [32].

(b) Methanogenic phase: Methanogenic phase is susceptible to the environment in that changes in environmental conditions like temperature would affect its required performance. Thus, it is best carried out in a tank with so many advantages which are found using a tank digester and this includes;

- The tank can be dislodged easily and efficiently; uncontrolled build up of organic sludge's would lead to loss of retention volume and eventual system failure.
- Rainwater dilution is reduced as volume/surface area ratio is high. Rain water is acidic and harmful on anaerobic process
- There can be no subsurface inflows or outflows into the system hence the process can be monitored very easily. In lagoons, the same uniformity is not possible.
- High gas production rates over a low surface area results in the break-up of scum formation which, if allowed to build-up will lead to loss of retention time [37]. Disadvantages can come in the corrosion of tank, which can be controlled by better protective paint work.

The digestion tank is completely closed and the biogas ratio (methane/CO_2) produced is higher in the two phase mode of operation than in the single phase indicating higher digesters rate and this gas is trapped and stored in a floating roof storage tank and may be used as energy source. The liquid discharged from the methanogenic phase is transferred to a sedimentation tank and offer over night settlement. The settled solids are recycled to the acidification ponds and the supernatant is discharged to the aerobic lagoon. To give room for maintenance, three tanks with a combined full load retention time of 20 days can be used [37].

The efficiency of an anaerobic system cannot be calculated by considering only the input and output BOD. The build-up of organic matter in the system has to be considered [36]. The digester tanks have to be dislodged periodically to minimize sand accumulations, such sludge have a high nitrogen content which are good replacement for fertilizer and withdrawal of 0.1 tonnes of sludge per tonne of feed is allowed [36].

(c) Aerobic phase: For a 20 tonne fresh fruit Bunch per hour (FFB/hr) oil mill, an aerobic lagoon with 20 days retention at 0.1 kg BOD: kg mixed liquid suspended solid (MLSS), a minimum of two 11 KW mechanical aerators can be used [38]. An extended aeration process is advantageous in the following ways:

- Operation is simple and the problem of solid generation and handling are reduced.
- Nitrogen destruction efficiencies are high

- Power requirement is not critical
- Construction costs are low
- Land usage is reasonable

After sedimentation the discharge from the digester is dumped in the aeration lagoon at the start. Twin aerators, operate continuously to provide mixing and oxygen transfers. The lagoon discharge is passed through a sedimentation tank and the settled suspended sludge is at present recycled to the acidification pond but can be used as fertilizer because of its high nitrogen content [38].

It is essential that the lagoon content are well mixed as failure will result to a build up of facultative condition in unstirred parts of the system. The process streams are shown on Fig. 3.

Process flow of the biological treatment plant: The liquid discharged from the tank is transferred to a sedimentation tank. The supernatant liquid from this tank overflows to the aeration lagoon. The concentrated digested liquid is recirculated into the digestion tank, to maintain a constant level of suspended solids in the digestion tank. When solids level exceeds the desired concentration, some of it is taken off into the sludge storage tank and sent to the decanter for dewatering. The sludge cake produced is mixed with fiber until a moisture content of about 60% is obtained. This mixture is then placed in the composting tank [38]. This process biological treatment plant is shown as Figure 4. Egbu [38], suggests that biological treatment methods is one of the most common ways of treating the effluent water. Also, the extent of conversion of the organic matter is measured by the ratio of BOD to COD. The ratio BOD: COD > 0.6 is ideal for biological waste treatment [39]. It was also found out that the aerobic treatment method is more effective and has a high process rate and enhances maximum destruction of carcinogenic products [39]. Biological treatment of the effluent is carried out in filter bed, biological pond; bio-filter and aeration are commonly used. Bio-filters are concrete wall reservoirs with perforated bottom, filled with packing of various sizes and inhabited by micro organisms. The microbes form a thin layer on packing surface. This effluent water is evenly distributed on the filter bed-layer to ensure contact with the microbes [40].

In all these effluent types, it is evident that anaerobic digestion is the most attractive biological process as it requires minimum power input [37]. Unfortunately, it operates within a relatively narrow range of physical conditions. However, the process is more stable with wider range if the acidic and methanogenic phases of digestion are separated [37]. After anaerobic digestion, the waste is normally still too strong for discharge to waterway and extended aeration and sedimentation provides a supernatant of low BOD. The settled solids from the anaerobic and aerobic digestion process are higher in nitrogen content than raw waste and are eminently suitable for use as fertilizer [32].

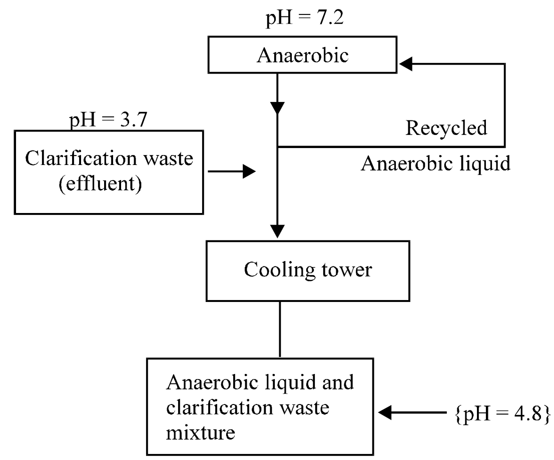

Fig. 3: Block flow diagram of the process showing stream

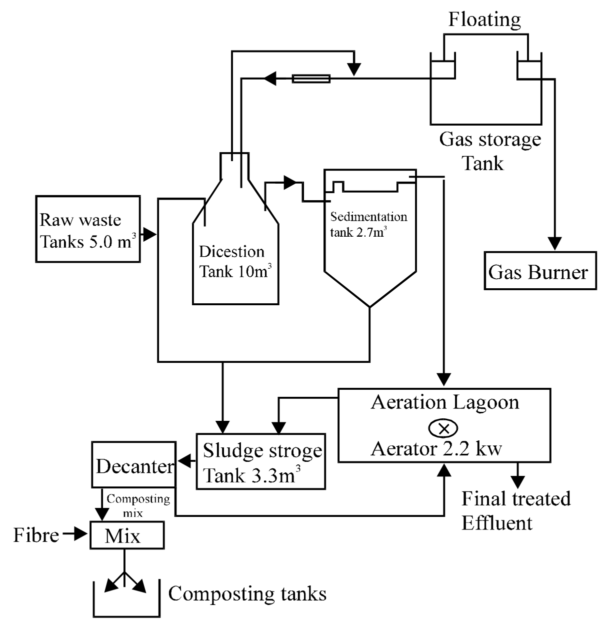

Fig. 4: Process for biological treatment plant

What actually happens is that the different palm oil mill effluent management methods are selected to optimize the BOD, the COD, total solids (TS), suspended solids (SS), oil and grease (O & G), Ammonical nitrogen, pH, temperature and cost. This effluent as stated earlier comes from three major streams, i.e., sterilizer condensate which contains oil, hydro cyclone waste which comes from kernel operation and finally separator sludge. All these amount to about 2.5 tons/ton of oil product and are highly polluting. Realizing the seriousness of the problem, there became the need to regulate the effluent [40].

Sludge treatment: The sludge fraction discharge from the tanks usually contains oil > 15%. The palm oil mill effluent ex-sludge is made up of mainly two other components in addition to the oil, which are water 93-94% and solids 3-4%, but the composition may very widely. If the oil is not recovered some what loses will be incurred in the form of effluent waste. The sludge fraction is therefore subjected to further treatment to recover the oil before discarding to the effluent pit.

The sludge fraction from the settling tank is routed to a holding tank (sludge tank), from where it is pumped to the sand cyclone. The sand cyclone separates the sand from the stream which will cause severe wear on down stream equipment. The stream is then routed to a rotating brush strainer where fibers and other solids are isolated by the sweeping operation of the rotating brush strainer. This is to avoid choking and blocking of the centrifuge (called sludge separator) which is responsible for this work [16].

These sludge separators are equipped with paring discs, sprawt wear resistant tungsten carbide nozzles and conical separating plates. When in operation, the centrifugal force exerted by splitting of the feed into a number of streams by the conical separating plates, causes the separation achieved eventually. The oil passes inward and the water and dirt passes outwards, part of water and dirt escapes over a gravity ring the size of which determines the position of the interface between the aqueous and oily zones. Oil fraction is usually recycled back to the settling tank while the water and dirt is discarded to the effluent. Efficiency of oil recovery in a sludge centrifuge is dependent on oil content of recycled stream over total oil content of feed. More especially, efficiency of sludge separator is gauged by the residual oil content of the centrifuge waste which includes dirties, H_2O, heavy sludge, sand etc. The variables affecting centrifuge efficiency are feed rate, nozzle diameter, feed temperature, dilution (viscosity) of feed oil and particles [16].

Analysis of samples from different treatment methods: We present the results from two methods of treatment of the palm oil mill effluent, to show the effectiveness of the various methods.

Table 2: Analysis of Samples from Digester tank and aeration pond

	Raw Effluent		Final discharge		
Parameter	Range	Mean	Range	Mean	% Reduction
pH	2.5-4.8	4.0	7.1-9.0	8.1	-
BOD	14190-42250	30800	20-290	120	99.6
COD	58590-110380	76090	590-5930	1460	98.1
TS	41520-97370	57030	3700-10420	6720	88.2
SS	17310-60360	27920	180-6990	1060	95.2
V.S	29420-6360	43490	1020-7180	2160	95.0
O & G	1790-31680	104050	6-100	30	99.7
NH_3-N	10-80	50	20-40	3	94.0
T-N	420-1400	1030	20-490	100	90.3

Source: Egbu, 2000. All parameter in mg/L except pH

Table 3: Analysis of Samples from Stirred Digester Tank and pond

	Raw Effluent		Final discharge		
Parameter	Range	Mean	Range	Mean	% Reduction
pH	3.1-4.7	4.0	7.0-7.4	7.3	-
BOD	10880-43750	27540	110-1800	610	97.8
COD	38840-100700	63400	340-19680	4820	93.0
TS	36920-84080	51690	6090-18400	10360	80.0
SS	9170-26090	19570	760-14850	4680	76.1
VS	31320-71650	43470	2680-14570	5000	88.5
O & G	1380-15040	8650	10-430	130	98.5
NH_3-N	20-50	40	60-300	180	35.0
T-N	600-1020	850	320-1070	520	38.8

Source: Egbu, 2000. All parameter in mg/L except pH

1. Digester tank and aeration pond: The result of this method of treatment is shown in Table 2. It was observed [36], that this treatment system exhibited encouraging performance through out the survey except for the third round sampling. In the third round, inevitable overloading had to be exercised because of emergency. Apart from this interruption, the treatment managed discharged levels of 120, 1460, 1060 and 100 mg/L of BOD, COD, SS and T-N respectively. The extended aeration in the operation has significantly removed the ammoniacal nitrogen (NH_3-N) which averaged about 3 mg/L in the final effluent [36].

2. Stirred digester tank and pond: Table 3 gives the results of the analysis of this system which comprises of stirred tank digestion followed by lagoon treatment. This treatment did not produce the kind of result obtained by the first method, the final discharge of BOD ranged from 110-1800 mg/L giving an average valve of 610 mg/L [36]. The inconsistency was mainly due to the practice of discharging the effluent directly into the lagoons, by- passing the digestion stage. Little attention was directed towards proper design and up keep of the lagoons. This was mainly because the anaerobic discharge was meant for land disposal for which it was only required to keep the BOD within 5000 mg/L. As expected, Nitrogen (N) removal was poor with final effluent levels of 180 and 520 mg/L of NH_3-N and T-N respectively [36].

CONCLUSIONS

It has been shown that a two- phase anaerobic digestion process is a practical method of treatment for palm oil mill effluent, from different sources. The system has a low energy demand for operation, the only power needed being that of pumping and it is stable in operation and can withstand sudden changes and over load conditions without loss of efficiency. If corrections of alkalinity are required, this is easily affected. The destruction efficiency achieved is of a very high order.

The extended aeration process has been demonstrated to be very suitable for the treatment of anaerobic liquids derived from palm oil waste. There are few operating problems and the true destruction efficiencies are high. The anaerobic and aerobic sludge are richer sources of nitrogen than raw waste or mixed anaerobic liquid and can be used as an advantage on the plantation as a substitute for commercial fertilizer.

Again, as a result of the environmental impact of the palm oil mill effluent, further research is still going on in the area of minimizing further the BOD load discharged to the environment and also other contaminants. Efforts are geared towards the use of boiler fly ash for adsorptive removal or reduction of BOD, colour and TSS [9, 41, 42]. The physical properties of boiler fly ash have been characterized [44] and thus, the application of boiler fly ash as an adsorbent is currently being investigated. Therefore, this will further reduce the contaminants in palm oil effluent, as this is a good example of using a waste to minimize another waste. Of course, this is a step in the right direction.

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