PALM OIL CLARIFICATION USING EVAPORATION

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ABSTRACT

A palm oil milling process to facilitate the treatment of the effluent discharged using zero-discharge technology cost-effectively has eluded the industry despite intensive efforts over several decades. A novel clarification process that significantly reduces the quantity of effluent discharged may provide the impetus for revolutionising the treatment, disposal and utilisation of effluent in palm oil mills. In the new process, a two-phase decanter is used to remove as much suspended solids as possible from undiluted press liquor to facilitate oil-sludge separation without the addition of water. Further, by making use of the large amount of oil in the feed as a fluidising agent, it is possible to use a multiple-effect evaporator system to remove a significant amount of water in the incoming feed in an energy-efficient manner. Oil-sludge separation after evaporation is to be achieved using equipment similar to that used in a conventional palm oil mill. The article examines the technical viability of the new clarification process based on pilot plant studies and explores its potential for making palm oil mills more environmental-friendly.

Keywords: palm oil milling, palm oil clarification, mill effluent, POME, zero-discharge.

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INTRODUCTION

An anaerobic/aerobic open ponding system has traditionally been used for effluent treatment, but silting of ponds due to high suspended solids concentration often reduces their effectiveness. The treatment of palm oil mill effluent (POME) to a final biological oxygen demand (BOD) of 20 ppm, as stipulated by the Department of Environment, Malaysia (DOE) in environmentally sensitive areas, requires the use of technology that can be expensive. The operating cost and power consumption of such plants can also be very high. The problems faced with biological treatment of effluent has prompted a search for alternative solutions for making palm oil mills more environmental-friendly. One solution is to modify processes in the mill so that the quantity of the effluent discharged is significantly reduced, thus making it viable to treat the effluent using zero-discharge approaches that were previously considered to be not technically and/or economically viable.

In the conventional clarification process, water is added to the liquor expelled from screw presses to reduce its viscosity to facilitate efficient oil-sludge separation by settling. Attempts have been made to reduce the amount of water added. Sulong and Tan (1996; 1999) used a membrane filter press to remove the suspended solids to enhance oil clarification without the addition of water. Junker (1999) proposed using a peeler centrifuge to remove the bulk of the suspended solids from the press liquor.

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Oil clarification after suspended solids separation in both of the above-mentioned systems is achieved with the use of a coalescence plate separator.

Graille *et al.* (1996) suggested the use of a centrifugal extraction technique which is widely used in olive oil factories. The process, called the DRUPALM process, does not set out to produce palm oil and palm kernel oil separately, but extracts both oils simultaneously. It consists of grinding the fruits to an oily paste, which is then heated to promote fat globule coalescence. Mechanical separation in a three-phase decanter produces an oil which contains about 95% palm oil and 5% kernel oil, that merely has to be purified to remove the impurities. By avoiding the use of a clarification tank, it is claimed that effluent generated by the process is reduced from 0.4 t in a conventional mill to 0.25 t per tonne fresh fruit bunch (FFB) processed.

The use of decanters in palm oil mills has aroused considerable interest since the 1970s, both for separating suspended solids from crude palm oil in a fairly dry state thereby reducing the BOD of the liquid effluent, as well as for clarifying the oil. Various clarification plant configurations incorporating two-phase and three-phase decanters have been tried (Diprose, 1978; Jorgensen, 1981; Roege *et al*., 1981; 1982; Jorgensen and Singh, 1982; Southworth, 1986; Lim, 1987; Singh, 1991). Three-phase decanters can be used either for primary separation (replacing the clarification tank) or for secondary separation of oil in the underflow from the clarification tank. Installing two-phase decanters prior to oil clarification can lead to reduction in the amount of water needed to facilitate oil clarification. In spite of the many studies carried out, much controversy still remains on the use of decanters in palm oil mills. Nowadays, decanters are normally used in large capacity mills, with or without sludge separators, for treating the underflow from the clarification tank since this leads to lower oil loss in the cake. No significant reduction in the amount of effluent is achievable in the latter case, since water must still be added to facilitate oil settling in the clarification tank.

The use of a special two-phase decanter that makes possible oil/sludge separation using a zero-dilution clarification process has been proposed by Hruschka (2003). The amount of effluent from a mill using continuous sterilisation and the zero-dilution clarification processes was approximately 50% of that from a conventional mill (Sivasothy, 2007).

The use of an evaporator system in palm oil mills has been attempted by Ma (1997) for removing moisture from POME. The high moisture content and the large quantity of raw POME means that the load on the evaporator system will be high. The need to burn empty fruit bunches to meet the very high energy demand of evaporation adds to the overall cost. Concentration beyond approximately 20% solids is not possible because the product becomes too viscous to facilitate the removal of moisture by evaporation.

EVAPORATION

Evaporation, a widely used method for the concentration of aqueous solutions, involves the removal of water from a solution by boiling the liquor in a suitable vessel, an evaporator and withdrawing the vapour. Evaporation is achieved by adding heat to the solution to vapourise the solvent. The heat is supplied principally to provide the latent heat of vapourisation, and, by adopting methods for recovery of heat from the vapour, it is possible to achieve great economy in heat utilisation. The principle heating medium used to facilitate evaporation is low-pressure steam. Evaporation differs from drying in that the residue is a flowable liquid instead of a solid. It is a unit operation that is used extensively in processing foods, chemicals, pharmaceuticals, fruit juices, dairy products, paper and pulp, and both malt and grain beverages. While the design criteria for evaporators are the same regardless of the industry involved, two questions always exist: is this equipment best suited for the duty, and is the equipment arranged for the most efficient and economical use? As a result, many types of evaporators and many variations in processing techniques have been developed to take into account different product characteristics and operating parameters.

Two commonly used evaporators currently are the falling film evaporator and the forced circulation evaporator. In a falling film evaporator, the liquid to be concentrated is supplied to the top of the heating tubes and distributed in such a way that it flows down the inside of the walls as a thin film. The liquid starts to boil due to the external heating of the tubes and is partially evaporated as a result. The downward flow, caused initially by gravity, is enhanced by the parallel, downward flow of the vapour formed. Residual liquid film and vapour is separated in the lower part of the calendria and in the downstream centrifugal droplet separator. It is essential that the entire film heating, especially in the lower regions, be evenly and sufficiently wetted with liquid. Where this is not the case, dry spots will result that will lead to incrustation and the build-up of deposits. For complete wetting, it is important that a suitable distribution system is selected for the head of the evaporator. Wetting rates are increased using longer tubes, dividing the evaporator into several compartments or by recirculating the product.

A forced circulation system permits the functions of heat transfer and vapour-liquid separation to be separated. The forced circulation evaporator was developed for processing liquors which are susceptible to scaling or crystallising. Liquid is circulated at a high rate through the heat exchanger, boiling being prevented within the unit by virtue of a hydrostatic head maintained above the top tube plate. As the liquid enters the separator where the absolute pressure is slightly less than in the tube bundle, the liquid flashes to form a vapour. The temperature rise across the tube bundle is kept as low as possible. This results in a high recirculation ratio. These high recirculation rates result in high liquor velocities through the tube which help to minimise the build-up of deposits or crystals along the heating surface.

The use of a multiple-effect evaporator system for the removal of moisture permits significant savings in the energy consumption. The significant energy savings can be explained by using the following example. If we consider the heat balance of a single-effect evaporator, we find that the heat content (enthalpy) of the evaporated vapour is approximately equal to the heat input on the heating side. About 1 kg hr^{-1} of vapour will be produced by 1 kg hr^{-1} of live steam, as the specific evaporation heat values on the heating and product sides are about the same. If the vapour produced is used as heating steam in a second effect, the energy consumption of the overall system is reduced by 50%. This principle can be continued over further effects to save even more energy. The theoretical steam consumption of a triple-effect evaporator system is therefore one-third of the steam consumption of a single-effect evaporator system for an equivalent evaporation load.

Single-effect evaporators are generally preferred when the throughput is low, when a cheap supply of steam is available, when expensive materials of construction must be used, as is the case with corrosive feedstocks, and when the vapour is so contaminated so that it cannot be reused.

Reduction in energy consumption is also possible by using either mechanical vapour recompression (MVR) or thermal vapour recompression (TVR) or by combining one of these two techniques with multiple-effect evaporation.

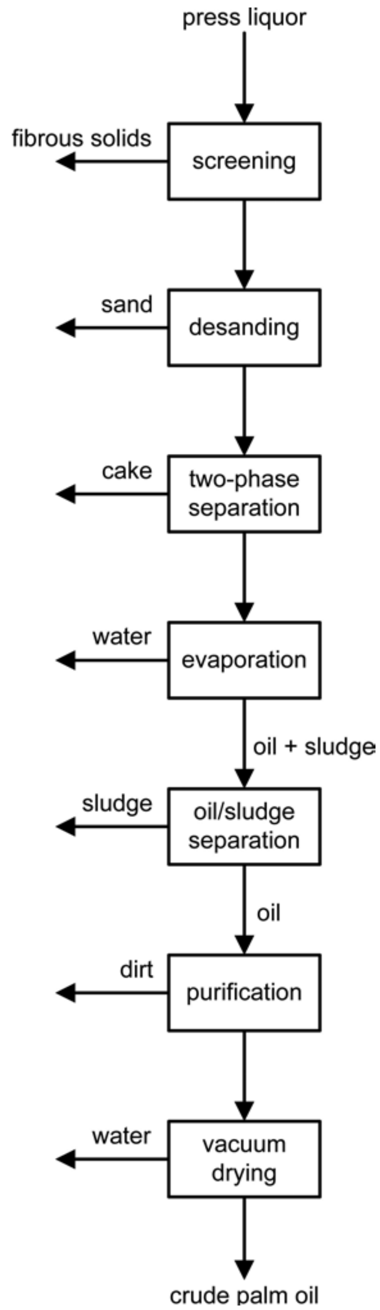

Figure 1. New palm oil clarification process.

PROCESS DESCRIPTION

Figure 1 illustrates the new clarification process. The feed to the new process is undiluted press liquor. To minimise the evaporation load, the addition of water to facilitate oil-sludge separation, as in the conventional clarification process, is avoided. The presence of organic suspended solids in the feed to the new process introduces a number of special considerations. To minimise the possibility of evaporator tube fouling, it is advantageous to remove as much of the suspended solids as possible using a decanter system prior to evaporation. This has the added advantage of minimising the oil loss with the decanter solids. Our preliminary studies indicated that the removal of water by evaporation prior to oil-sludge separation using a decanter tends to increase the carry-over of oil with the decanter cake.

The oil-sludge mixture discharged from the decanter is directly fed to an evaporator system. The reduction in moisture load on the evaporator system by avoiding the addition of water to facilitate the clarification process is about 200 kg per tonne of

FFB processed. This significantly reduces the size of the evaporator system required and its steam consumption.

A significant advantage offered by the new clarification process is that the large quantity of oil in the feed (approximately 40% to 50% of the feed) to the evaporator system acts as a 'fluidising agent' or 'carrier' to facilitate evaporation. The removal of water from the sludge in the absence of oil, as attempted by Ma (1997), will increase the viscosity of the sludge, reducing the heat transfer efficiency and increasing the rate of clogging up of evaporator tubes. In our process, the oil in the feed keeps the viscosity of the oil-sludge mixture low, permits high heat transfer rates and prevents fouling of heat transfer surfaces as the water in the sludge is evaporated. The amount of water that can be evaporated will depend on the ease of the subsequent separation of the dehydrated sludge from the oil. Initially, only free water is removed by evaporation, until a critical moisture content of the sludge solids is reached, when further evaporation removes the water that is bound to the sludge solids. Preliminary studies indicate that the removal of bound water may adversely affect the oil-sludge separation.

The use of a multiple-effect evaporator system permits the removal of moisture using a fraction of the energy required by a dryer system to remove an equivalent amount of moisture from POME, especially if hot air is used to supply the energy for drying. Reduction in energy consumption is also possible by using vapour recompression. TVR which uses a steam-jet booster to recompress part of the exit vapours, will probably be more suitable recompression method for use in palm oil mills. Through TVR, the pressure and temperature of the exit vapours is increased using steam at a much higher pressure and reused as heating steam. This gives the same steam/energy saving as an additional evaporation effect.

Our preliminary calculations indicate that a double-effect evaporator system should be sufficient and the additional steam required for evaporation can be met without having to utilise the empty fruit bunches as a fuel source.

The falling film evaporator used by Ma (1997) is the most widely used type of evaporator. As mentioned earlier, an essential part of the falling film evaporator is the liquid distribution system since the liquid feed must not only be evenly distributed to all the tubes, but also form a continuous film on the inner circumference of the tubes. Our preliminary studies, carried out using a falling film evaporator, indicated that settling of sludge solids in the tube header at low flow rates leads to the formation of flow channels making it difficult to uniformly distribute the liquid such that it flows down the inside walls of the tubes as a thin film.

The evaporator used in subsequent studies has therefore been changed to a forced circulation evaporator. This evaporator overcomes the problems encountered with feed distribution. In a forced circulation evaporator, the heating and vaporisation are separately carried out. Vaporisation is suppressed in the heat exchanger by back pressure generated by using an orifice plate or valve in the discharge from the heat exchanger. The suppression of boiling, together with the high circulation rate (turbulent flow) in the heat exchanger, result in less fouling than would occur with other types of evaporators. This increases the length of production runs between cleanings.

PILOT-SCALE CLARIFICATION SYSTEM

Figures 2 to *4* illustrate the pilot plant that is being installed for our studies. The pilot plant is capable of continuously processing approximately 2 t hr^{-1} of undiluted press liquor. The press liquor is first fed, without dilution, to a vibrating screen to remove coarse fibrous solids. The screened liquor is then processed using a hydrocyclone system for sand removal and heated to approximately 90°C before being fed to a two-phase decanter to remove a significant portion of the suspended solids in the form of a cake. The liquid phase from the decanter is then fed to an evaporator system to remove a significant portion of the moisture in the form of a distillate. The concentrated liquor from the evaporator system is discharged to a holding tank and is to be further processed using equipment similar to that used in a conventional palm oil mill to separate the oil phase from the sludge phase.

Low-speed mixers have been installed in the feed tanks of both the decanter and evaporator systems to minimise the effect of variations in the feed composition on their performance.

The pilot plant study is being carried out in two phases. In the first phase, we are focusing our attention on studying and fine-tuning the performance of the upstream components of the new clarification system, in particular the decanter system and the evaporator system. The performance of the decanter system is being evaluated for its abilty to remove suspended solids from undiluted press liquor and to estimate the oil loss with the decanter cake. The decanter used in the study is a Westfalia RCD 205 pilot-scale two-phase decanter with provision to change some of the settings to facilitate research studies.

The evaporator system used is an Alfa Laval single-effect forced circulation evaporator system, where a spiral heat exchanger is used for heating using steam, and a plate heat exchanger is used for condensation of the distillate. A spiral heat

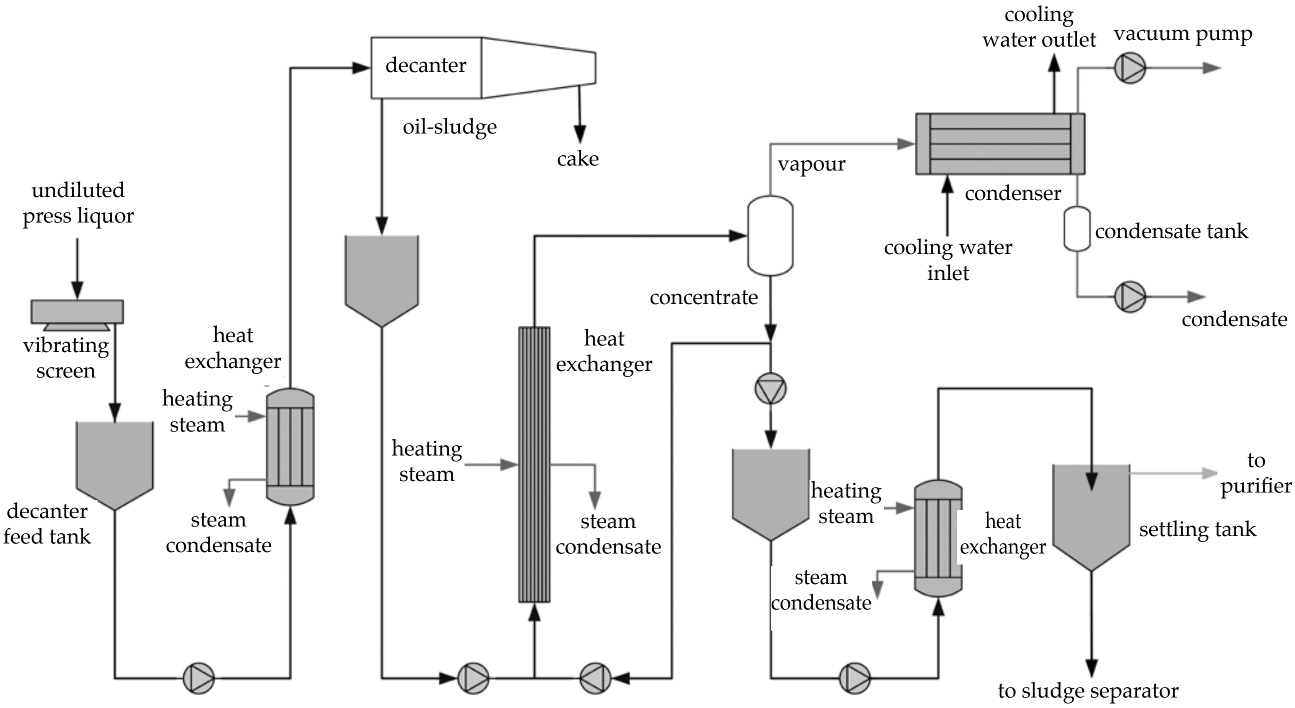

Figure 2. Pilot-scale palm oil clarification system based on evaporation.

Figure 3. Pilot-scale palm oil clarification system based on evaporation.

Figure 4. Pilot-scale palm oil clarification system based on evaporation.

exchanger is also used for heating the feed to the decanter system. The concentric spiral-shaped channel of this heat exchanger makes it suitable for the handling of fouling fluids. The curved channel optimises the heat transfer and flow conditions while keeping the overall size of the heat exchanger to a minimum. The design ensures that the fluid is fully turbulent at much lower velocity than in straight-tube heat exchangers and the fluid travels at constant velocity throughout the whole unit. This removes any likelihood of dead spots and stagnation. Solids are kept in suspension, and the heat transfer surfaces are kept clean by the scrubbing action of the spiral flow. This self-cleaning property ensures efficient heat transfer with minimum down time for maintenance and cleaning. Its design also permits easy access to the inside for cleaning and inspection with no special tools or lifting equipment required.

The effect of process parameters, such as steam pressure, recirculation rate and vacuum pressure, on evaporation rate is being studied. The effect of moisture removal on oil-sludge separation as well as oil quality is being evaluated. Deterioration in performance of the evaporator system due to fouling is also being monitored.

If no major problems are encountered in the first phase of the pilot plant study, the study will progress to the second phase. In this phase, the equipment to be used downstream to the evaporator system to facilitate the separation of the oil phase from the sludge phase will be installed, and an attempt made to assess and fine-tune the overall performance of the new clarification process.

PRELIMINARY ASSESSMENT

Assessment of Decanter Performance

The temperature of the liquor discharged from screw presses was generally about 90°C and further heating using the spiral heat exchanger prior to separation by the decanter did not lead to any noticeable improvement in the performance of the decanter. *Table 1* shows the typical decanter cake composition when the separation is carried out at 5400 rpm, which corresponds to a g-force of 3300 G. The use of a higher g-force will lead to better removal of suspended solids from the press liquor and produce a dryer cake with lower oil content. The use of a higher g-force will also minimise the carry-over of suspended solids to evaporator system, thereby minimising fouling of the heat exchanger.

To minimise wear and tear of the decanter scroll, it is essential that sand is removed from the feed to the decanter system. A trash removal system should preferably be used to remove as much sand as possible from the FFB prior to processing. Nevertheless, embedded sand particles picked up by the impact of bunches with the ground during harvesting and transportation are not so easily dislodged by such systems. Furthermore, screening methods that may be effective with feed that is dry may still be ineffective with damp and sticky feed material. Hence, it will be necessary to use a multi-stage hydrocyclone system to remove any sand still present in the feed-to-the decanter system.

Assessment of Evaporator Performance

Table 2 shows the composition at different stages of processing based on approximately 50% of the water in the incoming feed being removed by the evaporator system. The oil content rises from approximately 50% in undiluted press liquor to approximately 75% in the evaporated liquor. *Figure*

TABLE 1. ASSESSMENT OF DECANTER PERFORMANCE

Run	Decanter cake composition		
	% non-oily solids	% oil (wet basis)	% oil (dry basis)
1	31.39	4.94	13.81
2	26.80	3.92	12.76
3	30.56	4.06	11.73
4	26.56	3.81	12.54
5	25.73	2.92	10.20
6	25.59	4.19	14.08
7	25.28	3.51	12.17
8	27.04	3.51	11.47
9	26.05	2.98	10.25
10	24.26	3.59	12.90
11	24.29	3.53	12.71
12	23.97	4.14	14.74
13	21.68	2.68	11.00
14	25.95	3.84	12.88
15	23.80	2.95	11.01
16	23.37	3.10	11.70
Average	25.77	3.60	12.25

TABLE 2. APPROXIMATE COMPOSITION AT DIFFERENT STAGES OF PROCESSING

Component	Press liquor	Liquor after decanter	Liquor after evaporation
Oil	50.0	56.8	74.7
Moisture	43.0	39.1	19.9
Non-oily solids	7.00	4.10	5.40

5 provides a simplified mass balance for the new clarification process based on flow measurements carried out using the pilot plant. The amount of sludge discharged from the conventional clarification process is about 0.4 t per tonne of FFB processed. It is estimated that a significant reduction of about 83% in the amount of sludge discharged to about 0.068 t per tonne FFB processed can be expected by using the new clarification process.

Tables 3 and *4* show the oil quality at different stages of processing. Since the evaporation is carried out at low temperature and under vacuum conditions, the deterioration in oil quality is observed to be minimal.

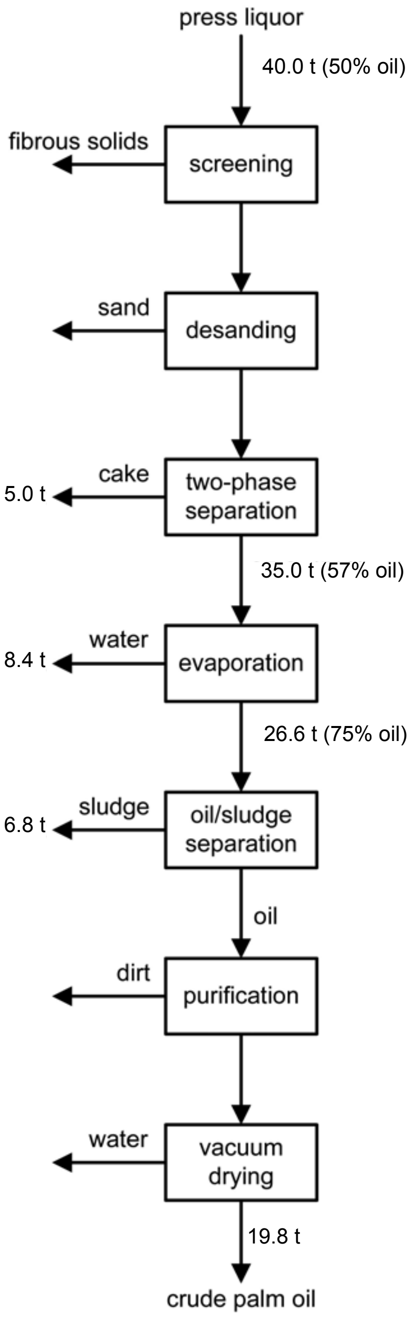

Figure 5. Mass balance on new palm oil clarification process (based on 100 t fresh fruit bunch input).

Settling tests and spin tests carried out on the evaporated liquor showed that separation into immiscible liquid phases should take place without difficulty due to suspended solids removal by the decanter system.

Of particular concern to us at this stage of the study is the problem of fouling of the heat exchanger used by the evaporator system. Fouling can be attributed to the increase in viscosity as a consequence of moisture removal. However, the problem is minimised by the presence of a large quantity of oil in the evaporated liquor. Fouling can also be due to product burn-on due to hot spots created by the use of high steam temperature, uneven heat distribution, *etc*. To minimise this likelihood, it is important to ensure turbulent flow conditions in the heat exchanger. Turbulence creates wall shear, a force that resists fouling.

At the end of each day's experiments, the evaporator system is cleaned by re-circulating hot water for about 1 hr before shutting down the plant. No progressive reduction in the evaporation rate due to fouling has been observed until now. Since the fouling does not appear to be significant, it has not been necessary to open up the heat exchangers to facilitate manual cleaning until now.

The use of high recirculation rates with the forced circulation evaporator system may lead to emulsification of oil droplets in the sludge phase, making subsequent separation of the oil phase from the sludge phase difficult. The problem may be accentuated by the shearing action of pump impellors. To minimise this likelihood, it is therefore preferable to use positive displacement pumps at very low rotational speeds.

An important component of the forced circulation evaporation system is the heat exchanger. Many different types of heat exchangers are currently available. Some heat exchangers that warrant consideration for our application are shell and tube heat exchangers, plate heat exchangers, corrugated tube heat exchangers and spiral heat exchangers. The factors that have led to the selection of the spiral heat exchanger for use in our pilot plant have been discussed earlier. Nevertheless, it should be stated that each type of heat exchanger has its merits as well as its shortcomings. It is probably worthwhile, at some stage, to carry out a comparative assessment of the different types of heat exchangers for our application.

If fouling is a concern in spite of the measures taken to minimise it, stand-by heat exchange equipment can be installed to facilitate intermittent cleaning using wash water without stopping the process.

TABLE 3. EFFECT OF THE NEW CLARIFICATION PROCESS ON OIL QUALITY

Run	% FFA		
	Press liquor	Liquor after decanter	Liquor after evaporation
5	2.73	2.74	2.74
6	2.79	2.95	2.95
7	2.31	2.32	2.32
8	2.99	3.02	3.02
9	3.05	2.97	2.97
10	2.78	2.74	2.74
11	2.50	2.49	2.49
12	2.86	2.82	2.82
13	3.19	3.16	3.16
14	3.86	3.81	3.81
15	3.42	3.43	3.43
Average	2.95	2.95	2.95

Note: FFA – free fatty acid.

TABLE 4. EFFECT OF THE NEW CLARIFICATION PROCESS ON OIL QUALITY

Run	DOBI		
	Decanter fed	Liquor after decanter	Liquor after evaporation
6	2.58	2.53	2.50
7	3.12	3.08	3.03
8	2.93	2.88	2.98
9	2.71	2.77	2.66
10	2.99	2.98	2.93
11	3.10	3.10	3.10
12	2.88	2.87	2.89
13	3.01	2.94	-
14	2.63	2.60	2.57
15	2.72	2.77	2.79
Average	2.87	2.85	2.83

Note: DOBI – deterioration of bleachability index.

CONCLUSION AND RECOMMENDATIONS

Although there is still considerable scope for further improvement of the technology used in this new clarification process, the preliminary studies carried out to date have demonstrated the new process to be technically viable. It has been shown that an evaporation step can be incorporated as part of the overall clarification process by using a two-phase decanter prior to the evaporation step to remove a significant portion of the suspended solids in undiluted press liquor. The study has also shown that the oil loss in the decanter cake is low and the separation of the two immiscible liquid phases in the evaporated liquor can be quite easily achieved. Comprehensive evaluation and further development of the clarification system will be carried out when the equipment to be used downstream to the evaporator system have been installed.

The ultimate goal of the research project is to achieve significant reduction in the amount of effluent discharged from the palm oil mill to facilitate treating the effluent using zero-discharge technologies. It has been shown that by using the new clarification process, the amount of liquid effluent leaving the palm oil clarification process can be reduced to about 6.8% of FFB processed compared to 40% with the conventional process. It is not our intention here to propose any particular technology for the treatment of this reduced quantity of sludge. Nevertheless, it should be apparent that the successful commercialisation of our technology will provide the following benefits:

i. Palm oil mills can be made environmental-friendly cost-effectively. The sludge can either be dried and used as an animal feed or fertiliser or mixed with empty bunches and converted into compost. The combined cost of installing the new clarification system and additional technology for achieving zero-discharge is expected to be lower than zero-discharge systems that have been proposed by others.

ii. The low processing temperature used will be beneficial to oil quality.

iii. The oil loss from the new clarification system is expected to be less than from the conventional system due to the lower quantity of effluent discharged.

iv. If a ponding system is not used for effluent treatment, the area needed for building the mill will be significantly reduced.

v. The significant reduction in the quantity of effluent discharged may make it viable to transport the effluent to a centralised effluent treatment plant.

vi. Some or all of the steam condensate and distillate from the evaporator system can be recycled, thus minimising the mill water consumption and water treatment cost.

A number of important issues have not been sufficiently addressed given the exploratory nature of the study. At some stage, it will be necessary to carry out research to identify appropriate zero-discharge technology for the treatment, disposal and utilisation of the effluent discharged from mills using the new clarification process. The distillate from the evaporation system appears slightly mirky and will probably also require some form of treatment before it can be discharged or be reused in the palm oil mill.

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