External Benefits of Environmental Regulation: Resource Recovery and the Utilisation of Effluents

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Summary

Since 1977, stringent environmental regulation has been progressively imposed on Malaysia's most polluting industry, the palm oil mills. The impact of the regulation on international trade and producer welfare has been quite small compared to the relative benefits to society in terms of changes in the levels of dissolved oxygen in the industrial effluents. External benefits from pollution abatement have been derived. This paper presents a preliminary evaluation of the derived benefits which have a long- term potential of recycling valuable resources while maintaining competitiveness in the international palm oil trade.

Introduction

The oil palm is one of the most versatile oil seed crops grown in the tropical world. Introduced into Malaysia in 1911, its cultivation has today expanded to more than 1.9 million ha, displacing rubber as the premier agricultural crop in the country. In 1989, Malaysia produced about 6.05 million t of palm oil contributing about 10 percent of the nation's export earnings. Malaysia also accounts for about 80 percent of the net world trade of oils and fats, which gives this country the distinction of not only being the leading exporter of palm oil, but also of being the largest single exporter of oils and fats in the world. The palm oil industry remains the third largest export earner of the country, after petroleum (including gas) and timber and its products. It contributed about 7.1 percent to the country's GDP in 1989. The industry also provides a source of livelihood to about 200,000 rural families in Government land schemes and private small-holdings, and employment opportunities to some 80,000 agricultural workers in estates. Employment opportunities are also created in the supporting industries, in trading, palm oil milling, processing and manufacturing sectors.

Along with this success, problems of waste disposal emerged with over 260 palm oil mills operating in the country. Wastes were dumped untreated into rivers. Palm oil mill effluent (POME), which is mainly organic, uses up oxygen in the rivers during decomposition when it is discharged untreated. The depletion of the oxygen level in rivers leads to anaerobic conditions and the release of noxious gases, particularly hydrogen sulphide. Thus, the natural ecology of the rivers is destroyed.

To relieve the problems of the indiscriminate discharge of such a large volume of effluents, the Malaysian Government passed the Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulation in 1977. Under this regulation palm oil mills were required to treat their effluents prior to discharging them into streams and rivers. A set of regulatory standards for the POME was

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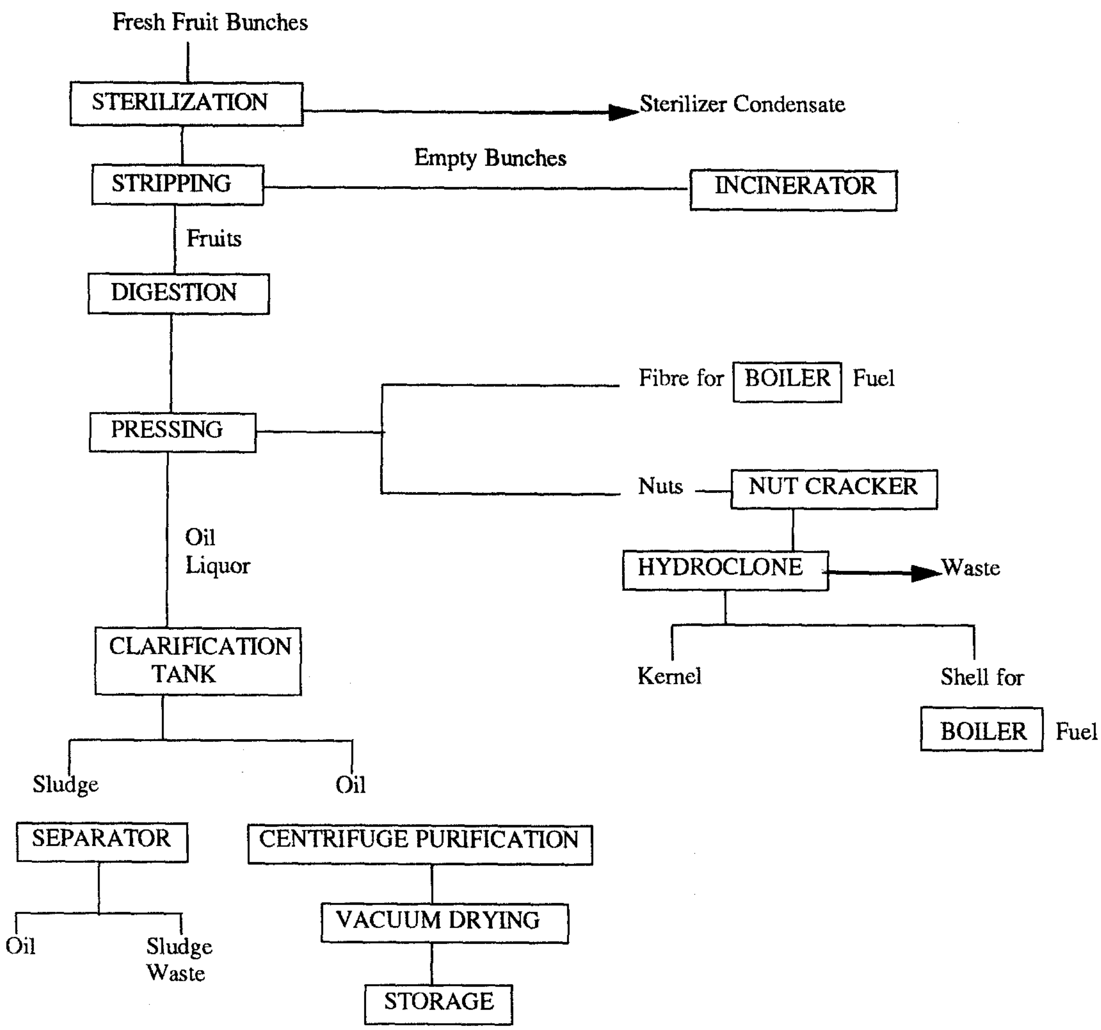

Fig.1 Conventional extraction process for crude palm oil.

established by the Department of Environment (DOE) to be complied with, and reviewed in stages, beginning 1st July, 1978.

Research was also intensified to find the solution to the problem. As the waste is unique to this region, the industry had to rely entirely on local expertise and it proved equal to the task. Various efficient treatment technologies for the palm oil mill effluents were developed and adopted by the Malaysian palm oil mills. The treatment systems were able to reduce most of the pollution control parameters to an acceptable level for disposal in water courses and by land application. Through research and development, beneficial uses for treated POME have been found. POME has tremendous potential for conversion into such useful by- products as animal feed and fertilizer, as well as being a source of energy. Over the years, it has been demonstrated that substantial cost savings and revenue have been generated by utilising the POME and the by-products from the mills and POME treatment plants.

Crude Palm Oil Production Technology and Effluent Generation

There were 261 palm oil mills operating in 1990, with a combined capacity of 9,695 t of raw materials, *i.e.* fresh fruit bunches (FFB) per hour. The palm oil milling process is more or less standard for all the mills. Palm oil comes from the mesocarp of the fruit of the oil palm. FFB's are usually harvested from the palms which are grown in plantations or small-holdings and delivered to the mills for processing. Fig.1 shows the stages involved in the conventional processing of crude palm oil (CPO).

Broadly, extraction of CPO consists of five main processing stages as follows:
(1) Steam sterilisation of FFB.
(2) Fruit stalk separation by stripping.
(3) Digestion of the stripped fruits.
(4) Oil extraction by means of a screw press.
(5) Clarification of the palm oil.

Liquid effluent is mainly generated from the sterilisation and clarification processes in which large amounts of steam and/or hot water are used. Another waste stream originates from the hydrocyclone operation where the broken shells are separated from the kernels. Under proper mill operation and management, the amount of effluent generated from the sterilisation process (sterilizer condensate), clarification (separator sludge) and hydrocyclone are respectively 0.9, 1.5 and 0.1 m^3 t^{-1} of oil produced (Whiting, 1979). These waste streams are normally segregated into different oil pits for oil recovery before they are mixed together for treatment. The characteristics of these wastes are shown in Table 1. The mixed effluent is commonly known as palm oil mill effluent (POME). The oil recovered from the oil pits is normally of poor quality. It is placed in drums and sold separately as technical oil for non-edible purposes.

POME, when fresh, is a thick brownish colloidal mixture of water, oil and fine suspended solids. It is hot (80–90°C), acidic (pH 4.5) and possesses a very high biochemical oxygen demand (BOD_3, sample incubated at 30°C for 3 days) which is 100 times as polluting as domestic sewage. The suspended solids in the POME are mainly oil bearing cellulosic materials from the fruits. The effluent is non-toxic as no chemical is added to the oil extraction process.

Besides the liquid POME, the palm oil milling process also generates a large amount of solid by-products, chiefly in the form of mesocarp fibres (press cake fibre), empty fruit bunches (EFB), *i.e.* stalk materials after fruit stripping, and shell.

Palm Oil Mill Effluent as a Major Environmental Problem

In the process of broadening the agricultural base of Malaysia's economy, more land has been developed, and the growing of oil palm has been encouraged to diversify agriculture away from the traditional export crop, rubber. A central feature in the growth of the agricultural sector has been the rapid expansion of palm oil output which contributed about 40 percent of the increase in agricultural output during the last two decades. Expanding output in the palm oil industry has had serious consequences to the natural environment in the country. In 1982, palm oil mills alone accounted for about 63 percent of Malaysia's total water pollution load. However, over the subsequent six year period, palm oil mills have substantially reduced the pollution load to 5 t per day, accounting for only 1.13 percent of the country's total water pollution load (Table 2). Today, domestic sewage is fast becoming the major contributor to the water pollution load.

Most of the public complaints regarding water pollution were directed at the palm oil industry and the natural rubber processing industry during

Table 1 Characteristics of palm oil mill effluent (POME). (Source: Whiting, 1979).

Parameter	Sterilizer waste	Hydrocyclone waste	Separator sludge	Effluent
pH	5.0	–	4.5	4.7
Oil and grease	4,000	300	7,000	6,000
BOD_3 [a]	23,000	5,000	29,000	22,000
COD	47,000	15,000	64,000	61,000
Suspended solids	5,000	7,000	23,000	18,000
Dissolved solids	3,400	100	22,000	21,000
Total nitrogen	600	100	1,200	800
Ammoniacal nitrogen	20	–	40	35

All units in mg L^{-1} except pH.
[a] Sample for BOD analysis is incubated at 30°C for 3 days.

Table 2 BOD load distribution, 1982–1988. (Source: Malaysia DOE, 1982–1988).

Source	1982 BOD generated (t day^{-1})	%	1988 BOD generated (t day^{-1})	%
Agro-based industries:				
Palm oil mills	1,760	62.7	5	1.13
Rubber mills	208	7.4	5	1.13
Manufacturing	124	4.4	19	4.30
Agriculture:				
Animal husbandry	NA	NA	55	12.44
Population: sewage	715	25.5	358	81.00
Total	2,807	100	442	100

NA = Not available.

Table 3 Source of water complaints 1978–1988 as percentages. (Source: Malaysia DOE, 1982–1988).

Source		1978–80	1981–84	1988
Regulation under Environmental Quality Act, 1974:				
Palm Oil Regulation:				
	Palm oil mills	28.3	20.5	17
Rubber Regulation:				
	Rubber mills	19.9	13.7	17
Sewage and Industries Regulation:				
	Animal husbandry	6.6	9.2	17
	Sewage	2.2	5.2	4
	Other industries	7.5	11.3	14
Non-Environmental Quality Act Regulations:				
	Mining and siltation	12.4	12.0	13
	Solid waste	4.9	5.6	1
	Other non-industries	4.9	5.6	17

the last decade (Table 3). The palm oil industry has traditionally been, and still is, the largest recipient of public complaints for water pollution. The raw effluent, when fresh, is a strong organic pollutant with BOD at discharge of more than 25,000 mg L^{-1}. The effluents have been discharged into water courses causing serious pollution. killing fish, prawns and crabs on which some fishermen depend. They leave unsightly sludge and stench on river banks and ditches.

Environmental Quality Regulation

Environmental consciousness in Malaysia can be said to date back from the 1920s when various Water Enactments (1920) and Mining Enactments (1929) were passed. In addition, the Forest Enactment (1934), the Land Conservation Act (1960) and the National Land Code (1965) are some of the other pieces of legislation containing provision for the protection of the environment. There are about 35 legal enactments which contain references that are related to environmental control, although these may not necessarily be devoted entirely to environmental matters. With environmental problems becoming more complex, these pieces of legislation have been found to be limited in scope and inadequate to deal satisfactorily with the newly emerging problems. The Environmental Quality Act 127 was therefore formulated in the early 1970s and made law by Parliament on 8th March, 1974.

The Environmental Quality Act, 1974, empowers the Department of Environment (DOE) with the mandate to accomplish national policies on environmental protection. It has as its main objectives the prevention, abatement and control of pollution and the enhancement of the quality of the environment.

Because of the pressing problems of the disposal of palm oil mill wastes, the environmental quality regulation for CPO mills was formulated. The regulation was cited as the Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulation, 1977. The regulation allowed a one year grace period for the palm oil mills to install treatment facilities, and then set four stages of allowable discharge standards. The mills were required to reduce the effluent components, using BOD as a critical parameter, from 20,000 mg L^{-1} to 5,000 mg L^{-1} in 1978, and to 500 mg L^{-1} by 1981. These BOD limits were further reduced to 250 mg L^{-1} in 1982, 100 mg L^{-1} in 1983 and 50 mg L^{-1} in 1986 (Table 4).

An interesting feature of the palm oil mill effluents regulation is the levy of effluent fees. Before 1979, dischargers were required to pay M$100 t^{-1} for BOD discharges exceeding the legal standard, and M$10 t^{-1} of BOD for loads equal to, or less than, the standard. Each discharger also paid a M$100 annual license fee. A large number of mills opted to pay high effluent fees (up to M$150,000 per mill in 1978) rather than implement the then available technology, which was capable of achieving only intermediate standards. A total of over M$3.5 million was collected in effluent related fees during 1978.

Since 1978, the regulation leaves firms the option of discharging POME onto land, subject to a BOD standard of 5,000 mg L^{-1} and a fee of M$50 per 1,000 t of effluent. Or, the effluent may be treated and discharged into watercourses subject to the BOD concentration standards and fees of M$10 t^{-1} of BOD up to the standard and M$100 t^{-1} of BOD load in excess of the standards.

Effluent Treatment Technologies

Since 1974, a considerable amount of research has been carried out to establish reasonably acceptable methods for treatment and disposal of palm oil mill effluents. Various treatment technologies have been developed with local expertise and a number of mills have installed treatment plants since that time. The three most common and efficient treatment systems adopted by the palm oil industry are the ponding system, the open tank digester and extended aeration system, and the closed anaerobic digester and land application system. The choice of which system is used depends very much on the individual mills, company policy, location and availability of suitable land.

Ponding system

The ponding system is by far the most popular treatment system used by the palm oil mills. More than 85 percent of the palm oil mills in Malaysia have adopted this system for the treatment of their POME (Ma and Ong, 1985). Various designs and configurations of the ponding system are used. The system is reliable, stable, and is capable of producing good quality final discharge with a BOD of less than 100 mg L^{-1} (Chan and Chooi, 1982; Chooi, 1984). The ponding system is cheap to construct, but it requires a large land area. Each anaerobic pond is usually 5 m deep and the facultative ponds are each 1–1.5 m deep. The hydraulic retention times (HRT) for the de-oiling tank, acidification, anaerobic and facultative ponds are 1, 4, 45 and 16 days, respectively.

The ponding system is normally operated at a low rate, with an organic loading ranging from 0.2 to 0.35 kg BOD m^{-3} day^{-1}. Because of the size and configuration of the ponds, they are quite difficult to control and monitor. Furthermore mixing (by the biogas generated) is hardly adequate. The biogas, which rises in the anaerobic ponds will carry with it fine suspended solids. Therefore, it is not uncommon to notice islands of solids floating in the anaerobic ponds. This often results in 'dead' spots and short circuiting in the ponds. Pond maintenance is labour intensive. Monitoring must ensure that as little oil as possible is allowed to flow into the ponds. If it does, the oil will agglomerate with the rising solids brought up by the biogas and form a sticky scum which is difficult to remove.

Due to the inadequate mixing by biogas, solids may build up at the bottom of the ponds, posing another maintenance problem for the mills. Excessive solids build-up at the bottom reduces the effective digestion capacity and consequently shortens the HRT. This adversely affects the treatment efficiency of the system. Regular desludging of the ponds is recommended. Submersible pumps are used for this purpose. The solids are pumped out of the ponds at regular intervals at a controlled rate to a series of drying beds constructed beside the ponds. The dried solids, which contain high plant nutrients, are used locally as fertilizers.

Table 4 Regulatory standards for palm oil effluent. (Source: Malaysia Department of Environment, 1983; PORIM, 1986).

Effective July Parameter	1978	1979	1980	1981	1982	1983	1986
Biochemical oxygen demand (BOD_3)[a]	5,000	2,000	6,000	500	250	100	50
Chemical oxygen demand (COD)	10,000	4,000	2,000	1,000	–	–	–
Total solids	4,000	2,500	2,000	1,500	–	–	–
Suspended solids	1,200	800	600	400	400	400	400
Oil and grease	150	100	75	50	50	50	50
Ammoniacal nitrogen	25	15	15	10	150[b]	150[b]	100[b]
Organic nitrogen	200	100	75	50	300[b]	200[b]	200[b]
pH	5.0–9.0	5.0–9.0	5.0–9.0	5.0–9.0	5.0–9.0	5.0–9.0	5.0
Temperature (°C)	45	45	45	45	45	45	45

All parameters in mg L^{-1}, except pH and temperature.
[a] Sample for BOD analysis is incubated at 30°C for 3 days.
[b] Value of filtered samples.

The energy required to operate the ponding systems is minimal. It is required only to run the pumps. Gravity flow is exploited wherever possible. For a 30 t FFB per hour mill, the energy demand is about 20 kW (Chooi, 1984). Only part time attendance is required to operate the system. The capital cost for ponding systems depends on the capacity of the palm oil mill. For a 30 t FFB per hour mill, the capital cost is about, M$330,000, excluding the cost of land.

Open tank digester and extended aeration system

In this system, after the oil recovery pit, POME is treated in a two-phase anaerobic digestion process followed by extended aeration in a pond. The digesters are open at the top and unstirred. Digesters with an individual capacity of about 600 to 1,300 m^3 are constructed. The hydraulic retention times (HRT) for the acidification, anaerobic and aerobic processes are 1, 20 and 20 days, respectively. The organic loading of the anaerobic digester is in the range of 0.8–1.0 kg BOD m^{-3} day^{-1}. Similar to the ponding system, mixing is provided by the biogas generated. Hence, this system faces the same problems of solid build-up at the bottom of the digester. In order to maintain a sufficient HRT for digestion, the solid has to be removed regularly as in the ponding system. The solids are normally carted away for land application on the local estates.

The digester supernatant is treated in an extended aeration pond. Oxygen is supplied to the aeration pond by mechanical aerators which is a very energy intensive process. The mechanical aerators used in such a system require an energy input of about 33 kW (Whiting, 1980). The amount of oxygen transferred by the aerators is perhaps too low and hence a long rotation time is required. The initial capital cost of such a system for a 20 t FFB per hour mill is about M$600,000 and the operation cost varies from M$0.30–0.60 t of FFB processed (Lim, 1984).

Closed anaerobic digester and land application

Tank digesters with individual capacities from 1,500 to 4,200 m^3 are used (Lim *et al.*, 1984). The digesters are operated at a conventional high rate system with an organic loading of 4.8 kg volatile solids (VS) m^{-3} day^{-1}. The hydraulic retention time (HRT) is about 10 days for operations at a temperature range of 42°C to 50°C. Good mixing is ensured by recycling the biogas through an emitter and a draught tube. Depending on the size of the digester, one or more mixers are required. Biogas generated from the digester is compressed and discharged into the emitter. From the emitter, the biogas rises through the draught tube in large bubbles. Thus, the digester liquor is drawn into the bottom of the draught tube and discharged from the top, causing the digester circulation and mixing. Such a mixing device is more economical to operate and easier to maintain than a mechanical one. Energy required for such a system is 1.8 kW per 1,000 m^3 digester capacity as compared to 14 kW for the mechanical stirrer. This system has been in operation for more than 10 years in some palm oil mills and very consistent performance has been observed.

In this system, the digester liquor, having a BOD of 500–2,000 mg L^{-1}, is applied to the

Table 5 Estimated fertilizer value from POME per annum.

Fertilizer	Tonnes (x1,000)	Price per tonne (M$)	Fertilizer value (M$ million)
Ammonium sulphate	75.5	424	32.01
Rock phosphate	19.5	225	4.39
Muriate of potash	68.6	474	32.52
Kieserite	59.6	300	17.89
Total	–	–	86.81

plantation as fertilizer. The biogas produced is harnessed for heat and electricity generation (Quah and Gillies, 1981). Excess biogas is flared off. The cost of two 4,200 m^3 anaerobic digesters sufficient to handle the effluent from a 60 t per hour mill, complete with gas mixer and a gas burner, is approximately M$950,000.

The Benefits of Pollution Abatement

Land application of digested POME

Research has established that POME in both raw and various treated forms contains very high levels of plant nutrients (Kanagaratnam *et al.*, 1981; Tam *et al.*, 1982; Quah *et al.*, 1982; Yeow and Singh, 1983; Lim *et al.*, 1984; Mohd. Hashim and Zin, 1984; Mohd. Tayeb Dolmat *et al.*, 1987). It has been estimated that the 15 million t of POME created in Malaysia have a fertilizer value amounting to M$86.8 million, *i.e.* 40.4 percent of the fertilizer expenditure in the oil palm estates in West Malaysia in 1988. The nutrient composition of the fertilizer is shown in Table 5.

Land application of POME is allowed, with prior approval, by the DoE if the BOD of the effluent is less than 5,000 mg L^{-1}. Its application to land has been shown to be beneficial to crops as well as to the soil properties. Crop yield increases of 10 to 24 percent have been reported (Tam *et al.*, 1982; Lim *et al.*, 1984). The yield improvement was attributed to the increased soil nutrients and moisture level provided by the POME. In most cases, the nutrients from POME have totally replaced the organic fertilizers needed under normal agronomic practices. Thus, tremendous savings in fertilizer bills have been realised in estates which own palm oil mills. It has been established that the water quality in the applied areas has not been affected (Mohd. Tayeb Dolmat *et al.*, 1987).

Solid from POME

In the 1970s, the treatment of POME was regarded as a burden to the millers. It was an investment with no financial returns. It is now recognised that POME has a tremendous potential for conversion into such useful by-products as animal feed and fertilizer, as well as being a suitable source of energy. Over the years, it has been demonstrated that substantial revenue can be generated by utilising the POME and the by-products from the mills and the POME treatment plants.

To date, a pollution prevention process (decanter-drier system) has been introduced to the palm oil industry. The decanter-drier system is one example of the preventive approach adopted by the industry towards reducing the amount of POME generated (Jorgensen, 1982). The introduction of the decanter-drier system into the oil clarification station has successfully reduced the volume of clarification sludge by 75 percent. The solid phase, with about 82 percent moisture produced by the decanter, is subsequently dried in a rotary drier, using the heat from the boiler exhaust gas. The system can not only reduce the amount of effluent generated, but it also eliminates air pollution problems. The dried solid thus produced (generally known as palm oil meal) has been shown to have great potential as both a soil conditioner and an animal feed (Jorgensen, 1982). Nutritionally, it is equivalent to rice bran, a conventional animal feed-stuff. In view of its economic benefits, the system has attracted much interest.

Biogas from POME

Anaerobic digestion is the primary process used in treating POME in Malaysia. In the course of anaerobic digestion, a valuable gaseous product – biogas is produced. About 28 m^3 of biogas can be obtained from every tonne of POME digested in a high-rate digester (Quah and Gillies, 1981).

Thus, for a 60 t FFB per hour palm oil mill producing 60 percent POME per FFB tonne, and operating for 20 hours a day, about 20,000 m^3 day^{-1} of biogas is obtainable. The biogas contains about 65 percent, 35 percent and 2,000 ppm of methane (CH_4), carbon dioxide (CO_2) and hydrogen sulphide (H_2S), respectively. It has a calorific value of about 53,000 kcal m^{-3}. It is being harnessed for heat and electricity generation (Quah and Gillies, 1981, Lim *et al.*, 1984; Chua and Gian, 1986). This has resulted in substantial saving in fuel oil bills.

Single cell protein (SCP) from fertilizer condensate

The proposed utilisation of POME as a medium for microbial growth for the production of single cell protein (SCP) has been made, mainly due to the non-toxic nature of the effluent and the fact that it contains all the necessary nutrients. There have been previous reports on this mode of utilisation using non- cellulolytic fungi (Greenshields, 1981). More recently, a process has been developed for the same purpose, using a thermophilous, cellulolytic fungus (designated as Isolate Cf-27) and taking advantage of the sterile condition of one of the streams of POME (namely, sterilizer condensate). The amino acid profile of the SCP produced shows that it is suitable for animal feed supplement (Cheah and Ooi, 1986).

Fibre, shell and empty fruit bunches

In addition to biogas, there are solid by-products that can be utilised as sources of energy. Fibres and shells are currently the main sources of energy in palm oil mills. They can produce more than sufficient energy to meet the mill's demand. Another good potential source of energy is the empty fruit bunches (EFB). EFBs constitute 23 percent of the FFB by weight. Recently, they were mainly being burnt for their ashes, which were used as fertilizers. Because of the air pollution problem, burning is now prohibited. Research has demonstrated that they can instead be used as mulches in local estates (Singh *et al.*, 1990). They can also be easily composted for use as fertilizer (Lim, 1990).

Conclusion

Besides palm oil and palm kernel oil, the palm oil industry also generates a number of by-products, most of which have well established uses. For Malaysia to maintain its position as the leading producer of palm oil, it is imperative that efforts are made to reduce the costs of production. To achieve this, a number of approaches are required, not the least of which is the dual maximisation of by-products utilisation. While several of the by-products are already effectively utilised, there is room for further improvement and progress. In recent years, there has been a great deal of interest in the utilisation of the empty fruit bunches (EFB) and palm oil mill effluent (POME). In this respect the EFB and POME, which are produced in technologically fixed proportion to crude palm oil (CPO), need to be optimally exploited to obtain maximum benefits from their uses. The EFB can either be used as fuel for the generation of steam power, or it can be returned to the field as mulches for oil palms. The POME, on the other hand, can be dried and used as a nutrient source for irrigating oil palms. Both these by-products, if fully exploited, will not only be an additional source of revenue to the industry, but more important, besides helping to further preserve the environment, they will save the country millions of ringgits in foreign exchange, especially in the import of expensive fertilizers and animal feed components.

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