RECYCLING OF AGRO-INDUSTRIAL WASTES THROUGH CLEANER TECHNOLOGY

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Summary

Agro-industrial wastes are organic matters which, through clean technology, can be recycled either by integrated waste utilization or simply returned to the place of their origin, nature. Sources and problems of agro-industrial wastes are reviewed for seafood products, palm oil and rubber industries. Agro-industrial wastes can usually be managed to be free of non-natural material, and so they could be appropriately recycled either by physical or biological means. Clean technology can be implemented to minimize waste, thereby increasing productivity and reducing the unit cost of the product. Successful application of clean technology requires full support from management, and full commitment from the clean technology team. Clean technology auditing is an effective procedure that includes five steps, namely planning and organization, pre-assessment, assessment, feasibility study, and implementation.

Recycling of waste is the key activity of clean technology. Wastes can be recycled on-site, off-site or by waste exchange. Waste exchange participation is strategically important as it employs the integrated approach of waste minimization. This leads to the concept of the biological industrial complex, which is a group of factories that share limited resources and recycling of wastes. Biorefinery is pointed out as the challenge for the future of clean technology, and is a combination of biological, physical and chemical science which is able to replicate an oil refinery using a biomass feedstock,

instead of fossil resources to produce industrial chemical and related products.

1. Introduction

Farming of fertile land reclaimed from forest was perhaps the first instance of using biofertilizer by man. The nutrient–rich soil of a forest is actually a result of biomass recycling. Fallen leaves and branches decomposed by insects and microorganisms gave man the insight of returning organic waste from agriculture to nature (*see also – Environmental Biotechnology – Socio-Economic Strategies for Sustainability*). The roof of the huts made from rice straw could be among the first use of agriculture residues, apart from firewood and wood clubs. Groups of men and women formed agriculture–based communities producing for their own consumption. However, as development progressed, agriculture became systematic and commercial.

Large-scale production at farms and factories started producing excessive amount of agricultural wastes of different kinds and forms. The development of the science and technology in the first stage was designed primarily to increase the productivity and processing of agricultural products. The belief that the environment was an infinite sink has resulted in the creation of technologies that are not "nature friendly", such as chemical fertilizer, insecticides, advanced (non-natural) breeding technology, harvesting, sorting, handling, storing, and processing. Agro-industry became a cluster of many disciplines including chemistry, plant science, soil science, irrigation, agricultural engineering, entomology, food technology, post-harvest management, process control engineering, biotechnology, and international trade and policy.

The growth of world population, the increase of per–capita energy consumption and the over–exploitation of natural resources have resulted in an imbalance in ecological systems. For agro–industries, the recycling of wastes (see *Recycling Livestock Excreta in Integrated Farming Systems*; and *Urban Rooftop Microfarms*) resulting in minimal discharge is one measure that leads to an environmentally sustainable industry. Waste recycling is one component, among others, of cleaner technology, a concept widely accepted as an effective tool with which to harmonize industry with the environment.

2. Sources and problems of agro-industrial wastes

Agro-industry, particularly the food industry, generates large amounts of liquid, solid and gaseous wastes, which emerge not only from processing operations but also from their treatment and disposal (e.g. sludge, H_2S). The wastes are therefore multi-phase and multi-component. The composition and quantity of agro-industrial wastes depends very much on the source of raw materials, as well as the nature of the products, operations, and processing steps. In general, food processing wastes consist of large amounts of organic material (carbohydrate, protein, fat, oil, etc.), with high values of BOD, COD, and suspended solids. Due to their high nutrient content, agro-industrial wastes have a high potential to cause severe pollution problems, if not properly managed or treated. This pollution can be divided into 3 main categories; waste water, solid waste, and air pollution, with noise pollution occurring in some factories. The characteristics of the pollution control problems in various agro–industries are illustrated in Table 1.

Industry	**Pollution Control Problems**		
	Water	**Solid Waste**	**Air**
Canning, Frozen and Dehydrated Fruits and Vegetables, Soup, Potato Chips, Specialty Items, Baby Food, etc.	Large seasonal volumes. Variation in effluent strength and volume. High biodegradable effluents. Some soluble organics difficult to remove chemically. Water coloration by strong pigments in some raw products. Liquid wastes highly putrescible and can not be stored for long periods of time.	Highly putrescible waste from peeling and trimming which can not be stored for long periods of time.	Odors from food processing wastewater treatment and solid waste disposal. Visible moisture (steam plumes). Entrained material losses (particulates).
Edible Oils	High concentrations of fat, oil, and greases; BOD_5, suspended solids; dispersed organics; and dissolved solids. Fats, oils and greases difficult to remove to acceptable level for direct discharge to waterways. Highly biodegradable effluents. Relatively large volumes of wastewater	Production of large quantities of solid material as a by-product recovered as fertilizer or feed. Highly putrescible waste which cannot be stored for long periods of time.	Odors from processing operations if not properly operated and maintained. Odors from wastewater treatment and solid waste disposal. Visible moisture (steam plumes). Particulate emissions from handling beans or seed and pumace. Occasional toxin or allergen discharge specific to raw product.

Dairy	Highly biodegradable effluents. Variation in flow rates and characteristics. Whey from cheese production.		
Pickle	Brine, high dissolved solids in effluents.		
Peanuts		Disposition of peanut shells and hulls.	Roasting odor.
Tea	Evaporation effluent.	Tea - chest and spent tea disposal.	
Coffee	Evaporation and other effluents.	Coffee grounds.	Roasting odor.
Chocolate	Suspended fats in effluents.	Cocoa shells.	Roasting odor.
Fish and Seafood	Liquid wastes highly putrescible and can not be stored for long periods of time. Waste have water coloring properties.	Processing wastes such as crab, shrimp and other shells.	Smoke from processing. Visible moisture (steam plumes). Odors from waste disposal.
Red Meat	Highly biodegradable effluents. Liquid wastes highly putrescible and can not be stored for long periods of time. Relatively large volumes of wastewater.	Highly putrescible wastes from screening operations which can not be stored for long periods of time.	Odors associated with waste treatment. Visible moisture (steam plumes).
Poultry	Highly organic effluents, high in suspended solids and floating materials such an grease. Relatively large volumes of wastewater.	Highly putrescible wastes from screening operations which cannot be stored for long periods of time. Production of large quantities of	Odors associated with waste treatment.

	Highly biodegradable effluent. Fats and grease in high concentration.	solids such as entrails, offal, feathers, etc., which are used to make animal feed.	

Source: Middlebrooks, 1979

Note: 1. The appearance of red or pink wastewater occurring in many seafood and rubber processing plants was found to be the photopigment of photosynthetic bacteria such as *Chromatium* (Prasertsan and Choorit, 1988), *Rhodocyclus gelatinosus* (Prasertsan *et al*., 1993a).

2. Too high suspended solids (>30 mg/l). The growth of algae may be one of the causes due to the presence of nitrogen and phosphorus in the polishing pond.

3. Sludge. The implementation of dissolved air floatation (DAF) to remove oil and protein from the wastewater generates the primary sludge. Besides oil and protein, it also contains alum and polymer which are added during the DAF process. The excess sludge from the activated sludge process is produced in even larger quantity, up to 15%, and consists of biomass. It deteriorates very quickly and normally processes through dewatering and drying prior to the disposal as landfill. An alternative utilization is urgently needed to prevent the environmental problem caused by the disposal.

Table 1**.** Characteristic pollution problems of agro-industries

In general, water pollution seems to be the most serious problem (see *Health and Environmental Aspects of Recycled Water)* in many agro–industries, since solid wastes have a much higher opportunity for recovery or utilization, for example the use of seafood wastes for fishmeal production. Water is commonly used in food processing as an ingredient (e.g. brine, syrup), for washing the raw materials, process steam, cooling and cleaning. The volume of water used, and types and concentration of pollutants are extremely variable even in the same sector.

Among various sources of wastewater in seafood processing plants, the tuna pre–cooking water or tuna condensate is the strongest single stream line with high BOD values, and also contains protein, oil (8–22%), and chloride. The oil is oxidized very easily, particularly after exposing it to high temperature and sun light. It normally accumulates in the form of a thick layer of scum on the surface of the oil trap which is very difficult to remove, treat and dispose of. The high volume and concentration of organic matter in the wastewater has caused many plants to change from a low-cost ponding system to a high-cost, capital—and energy—intensive activated sludge process treatment system. Upflow anaerobic sludge blanket (UASB) systems were installed to treat the frozen seafood wastewater so that there is no excess sludge to be disposed off. The closed anaerobic system is also applied in order to solve the malodor problem (air pollution) commonly occurring in open anaerobic ponds. The nuisance odor in the seafood factories is also due to the typical fishy smell from raw materials and steam plume of the precooking step as well as from the retort.

Palm oil is one of the edible oils produced mainly in tropical countries. Most of the crude palm oil is produced by the wet process, which consists of sterilization, digestion and oil extraction steps. The amount of solid wastes per one ton of fresh fruit bunch are;

250 kg of empty fruit bunch (EFB), 125 kg of palm press fiber (PPF) and 70 kg of palm kernel shell (PKS). The major problem with the solid wastes of palm oil mills is due to their surplus, despite the use of palm press fiber as boiler feed. The use of palm kernel shell is normally avoided since it causes black smoke, although its heating value (17.4 MJ kg^{-1}) is relatively high. Empty fruit bunches (EFB), the most abundant solid waste, is not suitable for boiler feed because of its high moisture content (about 60%) gained during sterilization. These unused wastes accumulate and occupy large areas in the plant and sometimes can be dangerous due to the possibility of self–ignition of piles of palm shell, or the growth of harmful microorganisms, like *Neurosprora*, on the moist EFB.

The effluent discharged from the palm oil mills is free of chemicals since only water is added during the process. In general, one ton of FFB generates 0.56 m^3 of palm oil mill effluent (POME) containing organic matter expressed as BOD and COD of 29.90 and 70.71 kg ton^{-1} FFB with suspended solids (SS), and oil and grease (O&G) of 12.8 and 8.15 kg ton^{-1} FFB, respectively. With the annual world production of palm oil being 94.34 x 10^6 ton FFB, the palm oil waste water is equivalent to the waste generated by 128 million people per year, assuming that one person produces 22 kg of BOD per year. High levels of suspended solids in the effluent are either floated or sedimented during wastewater treatment. The flotation in the form of scum on the surface of the anaerobic pond is partly the result of enzymatic reactions (e.g. xylanase), which set the oil droplets free and then move together with the solids to the surface. The high suspended solids can also be raised due to the flow of gas produced during anaerobic digestion. The sedimentation of solids reduces the capacity of the pond and the frequent sediment clean-up inevitably increases the cost of wastewater treatment. Treated wastewater is brownish, which is not allowed to be discharged into the natural waterways, despite the BOD value being within the specified limit. This gives no alternative other than reserving a very large area for the wastewater treatment system merely as reservoir.

The rubber industry is another important agro–industry in Southeast Asian countries, particularly in Thailand, Malaysia and Indonesia. Thailand's rubber industry ranks first among natural rubber producers and is moving towards finished products (disposable gloves, high pressure hoses and spare–parts for automobile) rather than concentrated latex or smoked rubber sheet as in the past. Water consumption in a concentrated latex factory can be very high, up to 3000 $m^3 day^{-1}$. The wastewater contains organic matter with BOD of 1500–6000 mg L^{-1} and suspended solids of 180–2000 mg l^{-1}. The malodor caused by the decomposition of the rubber and various chemicals (acids, alkali, ZnO_2, TMTD, DAP, etc.) added during the process is the main air pollution problem. The air pollution problem from the palm oil mill arises from the smell of volatile fatty acids or other sources along the processing line and also from the particulate emitted from the burning of EFB in furnaces.

3. Waste management hierarchy

Environmental problems in agro-industries could be reduced significantly if good waste management is employed. Implementation of this practice aims to prevent pollution and other environmental problems as well as to promote economic benefits, such as the conversion of wastes to by-products, and reduction of waste treatment costs. Waste management can be divided into four categories, which should be implemented in the following prioritizing order.

3.1. Waste minimization or waste reduction

Various measures have to be considered, with in-plant modification as the major approach. The applicable methods depend on local conditions, but there are two main practices in waste minimization.

3.1.1. Waste conservation.

The first step to be taken as an efficient preventive measure to avoid or minimize the generation of wastes is waste conservation. Energy conservation has been enforced in some countries, because energy production particularly from fossil fuel is considered as an environmentally polluting sector. It is obviously cheaper not to produce waste in the first place, especially when the consequences are very costly. Resources should be efficiently used for optimum economic benefit and environmental protection. Some of the possible waste conservation approaches are: keeping waste solids in bulk whenever possible and dispose of the wastes as a solid or as a concentrated sludge; and using high pressure to minimize water usage in clean-up processes or to maintain sanitation. A typical example of waste reduction at site is the semi-processed raw material in a crab meat canning factory in Thailand. The factory set up fisherman cooperatives to supply the crab meat instead of the whole crab. As a result, there is no bulky solid waste of shell and waste water from washing and cooking at the industrial site, but the wastes still exist somewhere else. Unless the crab shell is used for chitin—chitosan production or other products—overall waste conservation is not achieved.

3.1.2. Waste segregation.

Segregation of solid wastes, such as bone and small fragments of fish from wastewater by a hydroscreen, or removing suspended solids in palm oil mill effluent by decantation, not only minimizes the settleable solids from wastewater but also reduces the waste load and treatment cost. Wastewater discharged from various process operations should be separated according to the characteristics of the wastewater. Grease wastes, non–grease wastes, clear water from chilling, condensing and cooling operations, surface drainage, sanitary wastes, etc. should be collected and treated separately. This approach is necessary if effective by–product recovery, recycling, and reuse is to be achieved.

3.2. Waste utilization (reuse, recovery / recycling)

Although waste minimization practices are conducted in the seafood industry, it is inevitable that wastes are still generated. The recovery, reuse, or recycling of wastes for further utilization is therefore essential as they might be raw materials for the production of other valuable products. The recovery of solid, oil, protein from food processing effluent is in practice in most plants.

A good example of waste utilization exists in the tuna canning industry, where the tuna pre–cooking water (or condensate) is utilized for the production of fish extract, a flavoring agent, while the recovered solids are sold to a fishmeal factory. The waste materials could also be valuable as animal feed or fertilizer, or be further refined to produce many salable products.

Waste water from one process could be reused as process water of others, if it possesses acceptable characteristic. With this approach, the fresh water consumption and waste water generation in palm oil milling process could possibly be reduced by 65% and 67 %, respectively. In the years of soaring oil price, the biogas producing from the anaerobic treatment of palm oil waste water proved that investment is very attractive. The left-over solid wastes could be used for power generation feeding to the grid. There are many constraints on the economic utilization of wastes residues. Some of the major ones are:

- sourcing of waste residue because of seasonal and scattered availability and high transportation costs;
- variability of the quality of wastes and deterioration with time;
- lack of adequate or appropriate technologies and technical process information;
- absence of economic incentives and lack of assured market outlets for finished products attributable to consumer prejudices and habits;
- inadequacy of industrial infrastructure to support this potentially important emerging sector;
- shortage of funds and manpower for incentive R&D work in waste utilization; and
- inadequate managerial and administrative initiatives to develop and promote schemes to entrepreneurs for commercialization.

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Biographical Sketches

Poonsuk Prasertsan, born in 1953, studied in Food Science & Technology at Kasetsart University, Bangkok (1973–1977). She worked in a fruit and vegetable canning factory for nearly two years, then decided to study for a Masters Degree in Biotechnology at the University of Queensland (UQ), Australia (1979–1981). After graduation, she worked as a lecturer at Prince of Songkla University (PSU), Hatyai. She received an AIDAB Scholarship to pursue Ph.D study (Biotechnology) on enzyme (cellulase, xylanase) production at UQ (1983–1987). After receiving her doctorate, she continued her academic career at the Department of Industrial Biotechnology, Faculty of Agro-Industry, PSU and teaches in Biotechnology, Fermentation Technology, Enzyme Technology, Waste Utilization, and environmental related subjects, at graduate and postgraduate levels. Besides teaching, she has been active in research in the field of waste utilization and treatment, as well as clean technology. She has been a research fellow under the JSPS Program in Biotechnology several times and has received the Certificate for Lead Accessor Course in ISO 14000. In 1993 and 1995, she was involved in the projects entitled “Oil Recovery from Palm Oil Mill Effluent” and “Environmental Management Guidelines for the Palm Oil Industry”, supported by Deutsche Gessellschaft fur Technische Zusammenarbeit (GTZ), Germany and the Department of Industrial Works, Ministry of Industry, Thailand. She is now working on several projects such as process development for the production of photosynthetic bacteria and their applications; valuable products from agro-industrial wastes particularly seafood processing and palm oil mill wastes; biopolymer production from thermotolerant isolates and the strains isolated from wastewater treatment plant.

Suteera Prasertsan was born in 1953. He graduated with a BE degree in mechanical engineering from the Prince of Songkla University followed by Master and Doctoral degrees in mechanical engineering from University of Queensland in 1987. His main research is in the areas of energy technology and energy conservation. In 1998 his work on energy efficient brick kilns was recognized by a prize from the National Research Council of Thailand. He is currently an associated professor at the Faculty of Engineering, PSU. In addition, he is now working for the Thailand Research Fund, a research granting agency, as a rubber and rubber wood research program coordinator.

Aran H–Kittikun, born in 1949, has a B.Sc. in Food Science and Technology, an M.Sc. in Microbiology from the Kasetsart University (1970–1975), and a Ph.D in Biotechnology at the University of New South Wales (1980–1984) on the regulation of secondary metabolite production from marine bacterium, *Alteromonas rubra*. After receiving his doctorate, he worked at the Department of Food Science and Technology, Chiang Mai University and undertook research on microbiological change of Nham (traditional fermented pork). He then moved to Prince of Songkla University at the Department of Industrial Biotechnology, Faculty of Agro–Industry. He has been a research fellow under the JSPS program in Biotechnology for many years and has a certificate for Lead Accessor Course in ISO 14000. His research interests include fermentation and enzyme technology and cleaner technology. In 1993 and 1995 he received grants from Deutsche Gessellschaft fur Technische Zusammenarbeit (GTZ) and the Department of Industrial Works, Ministry of Industry for research on oil recovery from palm oil mill effluent and preparation of environmental management guidelines for the palm oil industry. He is now working on the production of fatty acids and monoglycerides from palm oil by immobilized lipase and is actively involved in the application of cleaner technology for the agro-industry of southern Thailand.