Sustainable Treatment of WasteWater from Agro-Food Industry

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Abstract:

Wastewater from the agro-food industries, especially the palm oil mills, is a hazard to the environment and should be appropriately treated and managed.The conventional Effluent Treatment Pond System is able to lower the BOD (biological oxygen demand) level of POME (palm oil mill effluent) from 25,000 to 30,000 ppm to less than 100 ppm.Biotechnology is being applied in the anaerobic digestion of the complex organic materials in the POME. Over the years, the regulations have become stricter and the waste waternow need to be treated more quickly and more efficiently. Biogas,which is generated in the anaerobic digestion of POME isa greenhouse gas (GHG) and palm oil millers are required to install biogas plants to capture the biogas.Waste water treatment helps to protect public health and environment. Biogas capture minimises the emission of greenhouse gases into the atmosphere. Renewable energy is recovered from the captured biogas by converting it into bio-Power or into bio-CNG.

Keywords: anaerobic digestion; palm oil mill effluent; biogas; sustainable wastewater treatment

Waste Water from Agro-food Processing Industries

A large amount of water is used in the agro-food processing industries, such as, for initial cleaning of the raw material, fluming, blanching, pasteurizing, cleaning of processing equipment and cooling of finished product. The water used is identified by the water quality requirement for different applications. For example, the best quality water is required for use in the food and independent water treatment is undertaken to assure complete freedom from odour and taste and to ensure uniform water condition. If the processing steps involve a large amount of materials, then a great amount of solid waste is potentially introduced into the waste water.

Most of the water that is used in the agro-food processing industries ends up as waste water. The waste water contains high quantities of organic material, a high level of biodegradables and variable pH levels. If this waste water is discharged into a stream or waterway, the organic waste will utilize the dissolved oxygen in the waterway during the process of stabilizing. It will degrade the water body by reducing the dissolved oxygen value below what is required by normal aquatic organisms.

The wastewater, from the processing of fruit and vegetables,will contain organic matters and will cause high levels of biochemical oxygen demand (BOD) and total solid and suspended solids (TS and SS).The waste water that is produced by the seafood and meat industries contains high loads of organic matters due to the presence of oils, proteins and suspended solids. Moreover, it might also contain high levels of phosphates and nitrates. In the canning phase, the waste is also produced from the spillage of sauces, brines and oil in the can filling process, together with the condensate which was generated during precooking. The typical characteristics of waste waters from different agro-food industries are presented in Table 1.

Table 1. Characteristics of Wastewaters from Agro-food Industries (Rajagopal et al., 2013, Parveen et al, 2010)

Industry	TS (mg L^{-1})	TP (mg L^{-1})	TN (mg L^{-1})	BOD (mg L^{-1})	COD (mg L^{-1})
Food Processing	-	3	50	600-4000	1000-8000
Palm oil mill	40000	-	750	25000-30000	50000-100000
Sugar beet processing	6100	2.7	10	-	6600
Dairy	1100-1600	-	-	800-1000	1400-2500
Corn milling	650	125	174	3000	4850
Potato chips	5000	100	250	5000	6000
Baker's yeast	600	3	275	-	6100
Winery	150-200	40-60	310-410	-	18000-21000
Cheese dairy	1600-3900	60-100	400-700	650-6250	400-15200
Olive mill	75500	-	460	-	130100
Cassava starch	830	90	525	6300	10500

Note: TS=total solids; TN=total nitrogen; TP=total phosphorus; BOD=biochemical oxygen demand; COD=chemical oxygen demand (Rajagopal et al., 2013)

Discharging the waste waters into the water bodies can cause eutrophication and oxygen depletion. Oil-containing wastewater can pollute nearby beaches and shores along the surrounding coastline. The wastewaters, produced by the agro-food industries, are a hazard to the environment and needs to be appropriately treated and managed, in particular, the waste water from the palm oil mills. Waste water from palm oil mills has one of the highest TS, TN, COD and BOD values as shown in Table 1.

Waste water from Palm Oil Mills

A palm oil mill generates about 0.65 to 1.0 metric ton of wastewater for every metric ton of fresh fruit bunch (FFB) that is processed. Malaysia processes about 90 to 100 million tons of fresh fruit bunch (FFB) annually and produces about 18 to 20 million tons of crude palm oil (CPO) annually. At the same time, it produces about 70 to 90 million ton of wastewater or palm oil mill effluent (POME) annually.

POME (palm oil mill effluent) is a mixture of the condensate from sterilization process, the sludge from oil clarification process, the water from hydro-cycloneand the wash water from mill cleaning. They are all drained into the mill sludge pit. POME is dark brown colloidal slurry of water, oil and fine cellulosic materials. Its temperature is about 80 to 90°C. In addition to the organic contents, POME also contains inorganic minerals, particularly phosphorus, potassium, magnesium and calcium. POME is about 95% water, 0.6 to0.7% oil, and 4 to 5% total solids, including 2 to 4% suspended solids, Chemicals are not added during the production of palm oil and so,POME is a non-toxic wastewater (Parveen et al, 2010).

StringentStandard for Discharge of Treated Wastewater

In the early years of development of the palm oil industry, the common practice by the palm oil mills was to discharge the untreated palm oil mill effluent (POME) directly into the water courses.In 1978, the indiscriminate environment polluting activities were put to a stop with the enactment of Environmental Quality Regulations (MPOB, 2019). The POME must be treated to a biological oxygen demand (BOD) level of less than 5000 ppm before the treated wastewater can be discharged into water courses.

Over the years, the amount of waste water from the palm oil mills increased as the production of palm oil in the country increased. The regulations became stricter to ensure the POME is treated and managed more quickly and efficiently. The Final Discharge Standard became stringent and the maximum allowable BOD value was reduced to 1000 ppm in 1980 and to 100 ppm in 1984 (MPOB, 2019).

In Sabah and Sarawak as well as in certain areas above the water intake points, a more stringent Final Discharge limit of BOD at less than 20 ppm has been imposed since 2006. Land application of the treated POME is encouraged. Near populated areas, zero discharge of the treated POME into water courses is permitted (MPOB, 2019).

Conventional POME Treatment Ponds

Most palm oil mills in Malaysia use the huge effluent ponds to treat the POME (wastewater). A typical effluent treatment pond system consists: a) oneCooling Pond, b) two Acidification Ponds, c) four Anaerobic Ponds, d) four Aeration Ponds and e) one Stabilisation Pond.The POME is pumped from the mill sludge pit to the Cooling Pond. The total Hydraulic Retention Time (HRT)provided is around 120 to 150 days.The effluent treatment ponds are able to lowerthe BOD of the POME from around 25,000 to 30,000 ppm to less than 100 ppm.Polishing plants (for tertiary treatment of POME) are being installed to reduce the BOD level of the POME to less than 20 ppm at the final discharge (Parveen et al, 2010).

In the Anaerobic Ponds, the organic materials in the POME are biologically degraded in the absence of oxygen and biogas is generated and emitted into the atmosphere. About 26 to 28 m^3 of biogas is emitted from every tonne of POME degraded. Biogas is a mixture of Methane (CH_4) at 50% to 70%, Carbon dioxide (CO_2) at 30% to 45%, Hydrogen sulphide (H_2S) at 1500-2500 ppm, moisture (H_2O) and minor impurities. Improper operation of the anaerobic digester will lead to low biogas yield.

Biological Processes in Anaerobic Digestion of Wastewater.

The processes in anaerobic digestion of POME involve three main stages, which are hydrolytic, acidogenic, and methanogenic. In the first stage, hydrolytic microorganisms secrete extracellular enzymes to hydrolyse the complex organic complexes into simpler compounds such as triglycerides, fatty acids, amino acids, and sugars. These compounds are then subjected to fermentative micro-organisms that are responsible for their conversion into short-chain volatile fatty acids(mostly acetic, propionic, butyric), and alcohols.

In the methanogenic stage, two separate biological transformations take place. Firstly, the acetic acid is converted into methane and carbon dioxide by methanogens. Secondly, the propionic and butyric acids are converted into acetic acid and hydrogen gas before being consumed by the methanogens.

The end products of the anaerobic digestion are methane and carbon dioxide. The biological oxygen demand (BOD) at the first two stages remains unchanged as when it entered the anaerobic treatment, because only the breakdown of the complex compounds to a simpler mixture of organic materials has occurred. The BOD is reduced significantly after the methanogenic stage.

The biological treatment of POME depends on the population and activity of the good micro-organisms in the POME to perform the bio-degradation process. Knowledge in biotechnology can be applied to enhance the biological treatment and management of the complex organic wastes to protect public health and environment

Biogas Capture to Production of Bio-power and Bio-CNG

MPOB (Malaysian Palm Oil Board) requires all mills to implement biogas capture by 2020 to minimise the emission of greenhouse gases (GHG) into the atmosphere. Palm oil millers are complying with directive. The biogas digester plantsthat are recently constructed have features that enhance the anaerobic digestion process and increase the production of biogas.

The biogas that is captured can be used as boiler fuel to replace the kernel shells which can be sold at a high market price. The captured biogas can be scrubbed to remove hydrogen sulphide (H_2S) and then used in a gas engine to generate electricity and sell to the national grid. The captured biogas can also be purified to remove and compressed to produce Bio-CNG (Nasrin et al., 2017, Nasrin et al., 2018). Bio-CNG has a methane (CH_4) content of 90 to 95% and can be fed into local natural gas grids. It can be used as fuel in vehicles and can also be used for heating purposes in industries. The estimated energy recovered from the biogas in converting to bio-power and bio-CNG are 31% and 86% respectively as illustrated in Figure 1, where more than 60 percent of energy is lost in the engine exhaust gases, when the gas is combusted in the gas engine (Jay Kemp, 2014).

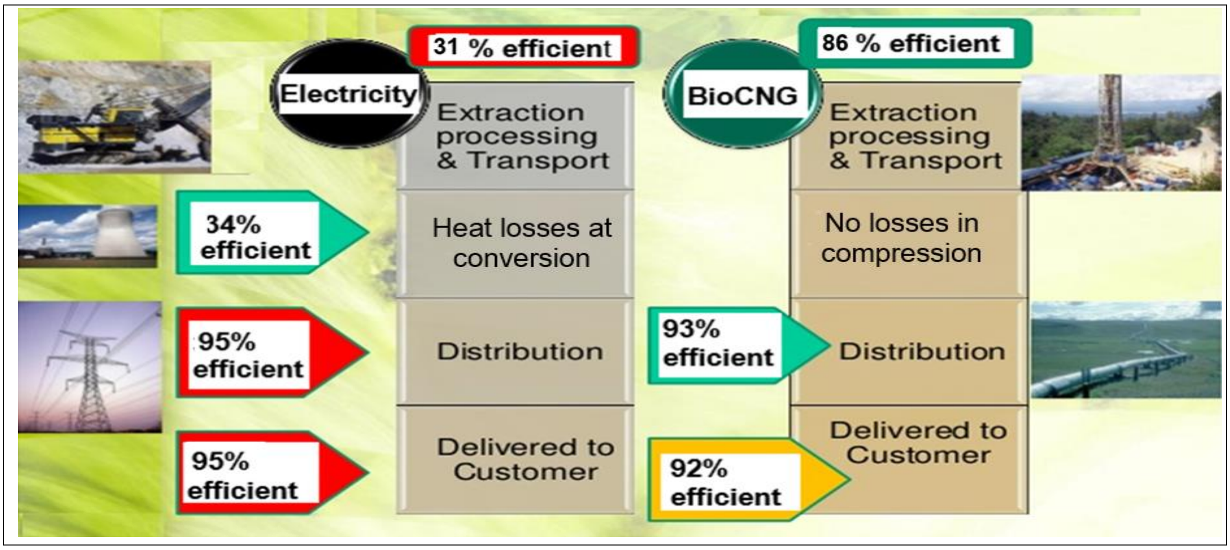

Figure 1. Efficiency of Energy Recovery from Biogas

Discussion

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Biogas is generated in the anaerobic digestion of POME. It is a greenhouse gas (GHG) and palm oil millers are required to install biogas plants to capture the biogas. The captured biogas can be used as boiler fuel to replace the kernel shells which can be sold at a high market price.

The captured biogas can also be combusted in a gas engine to generate electricity (bio-power)which can be used in the mill or can be sold to the national grid. The captured biogas can also be converted into Bio-CNG. The efficiency of energy recovery is around 31 percent when biogas is converted to electricity (bio-power) as compared to around 86 percent when converted to bio-CNG as presented in Figure 1. Bio-CNG can be used as green vehicle fuel to replace diesel, gasoline and CNG (compressed natural gas). It can also be used for heating purposes in industries and households to replace LPG (liquified petroleum gas) and CNG.

Conclusions

Waste water treatment helps to protect public health and environment. Biogas capture minimises the emission of greenhouse gases into the atmosphere. Renewable energy is recovered from the captured biogas by converting it into bio-Power or into bio-CNG.

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