Anaerobic Digestion of Palm Oil Mill

Ringkasan

Penghadaman secara penapaian tanpa oksijan adalah satu cara yang sangat luas digunakan untuk memproses effluen kilang minyak kelapa sawit di Malaysia. Kejayaan operasi penghadaman secara penapaian tanpa oksijan adalah bergantung kepada kefahaman proses teknologi. Rencana ini membincangkan secara ringkas asas-asas alat penghadaman, faktor-faktor yang mempengaruhi penghadaman dan perkara-perkara yang mengawal alat penghadaman itu.

Introduction

Anaerobic digestion is the breaking down of organic materials in the absence of air or more particularly oxygen. These materials are broken down biologically by bacteria which come in all types, sizes and shapes. These bacteria grow in the absence of oxygen, i.e. under anaerobic conditions. Hence they are often called obligated anaerobes. They obtain energy from the oxidation of complex organic matter and convert it into end products consisting of liquid, gases (mainly methane and carbon dioxide) and stabilized solids.

Anaerobic digestion of organic matter is considered a two-stage process brought about by two distinct groups of bacteria as shown below:

Organic Matter + Acid Forming Bacteria K_1 Organic Acids + Methane Forming Bacteria K_2 Solid + Methane + Carbon Dioxide

← First Stage →← Second Stage →

The constants K_1 and K_2 represent, respectively, the rate of production of the intermediate products (organic acids) and the rate of breakdown of these intermediate products to methane and carbon dioxide. For a balance and continuous digestion operation, K_1 and K_2 must be approximately equal or K_2 must be greater than K_1, so that the digester would not turn sour due to increase of volatile organic acids. The values for K_1 and K_2 are not known for palm oil mill effluent digestion. However, it is believed that K_2, the rate of conversion of volatile organic acids to methane and carbon dioxide is limiting to the total reaction.

Digestion Systems

Digester

Generally, there are two types of digesters used in palm oil mills. The simplest digester is a circular, unheated, open-top tank, whose contents are mixed naturally by rising gases.

In this particular system, the acid phase is separated from the methanogenic phase. The acid phase takes place in an open pond. *Whiting and Lim (1981)* reported that acidification process took place in two days retention. The feed to the digester in this case consists of a mixture of equal amount of supernatant liquor from the digester and raw effluent. The feed enters the centre of the active zone where digestion takes place, as shown in *Fig. 1.* The stabilized sludge or solids settle to the bottom. As gases are formed they rise to the surface, pass through the scum layer and escape into the atmosphere. The rising gases carry the lighter solid particles to the surface above the supernatant and form a dense layer of scum. The accumulation of solids at the bottom and scum at the top greatly reduce the effective capacity of the tank. Hence a proper desludging programme is required to ensure that the digester is not overloaded. The other disadvantage reported are the corrosion of the tank upperworks resulting from condensation of H_2S on the structure and adequate foundation to withstand the full capacity. In this system, a hydraulic retention time of twenty days is reported to be adequate.

The other type of digester used for palm oil mill effluent is the single, mixed and covered digester as shown in *Fig. 2.* The digester content is mixed by a mechanical horizontal stirrer. In this case more bacteria are exposed to the food and a faster reaction takes place. The two reactions (acid forming and methane forming) are expected to take place simultaneously in the digester. Mixing reduces the layering effect mentioned in the unmixed system. Complete digestion is expected over a shorter time (about eighteen days) and hence a smaller digestion tank is required. In this covered digestion system, a useful by-product, biogas is produced. About 1.4 m^3 biogas is produced for every kg. of BOD destroyed. Thus if a mill produces 360 m^3 of palm oil mill effluent per day with 5% solid content and 25000 mg/l of BOD is destroyed in the anaerobic digestion process, 12000 m^3 of biogas is also generated. The gas is being used to generate electricity or for other purposes.

Anaerobic ponds

This is by far the most popular system adopted by the industry. This consists of a number of ponds connected in series or in parallel as shown in *Fig. 3.* Typically, an anaerobic pond is a deep (5m – 6m) earthen pond with appropriate inlet and outlet piping facilities. Usually there is an acidification (two days retention) before the anaerobic ponds. A total retention time of about thirty days is considered to be adequate. For flexibility and emergency measures, ponds with retention time up to hundred days have been constructed in some mills.

The mechanism within the pond is similar to that of the open – top digester mentioned earlier.

Digester Operation

Loading

An analysis of the loading data collected from the working digesters at mesophilic range is given in *Table 1.*

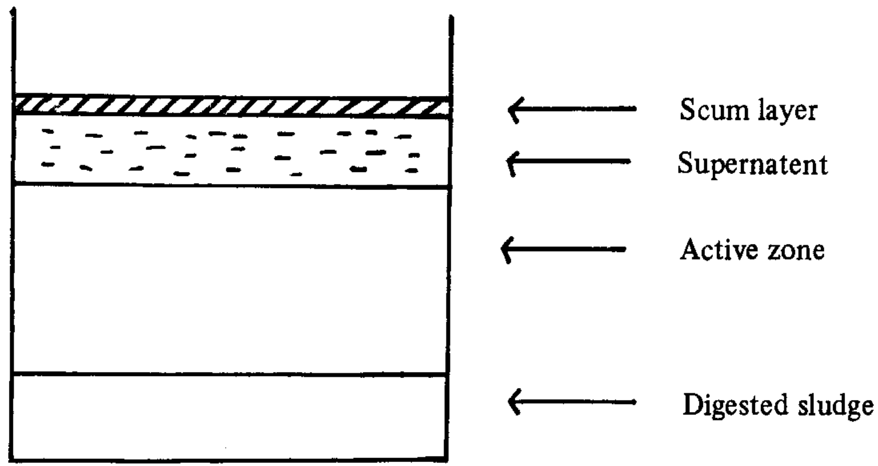

Fig. 1. Open-top, Unheated, Unmixed Digester.

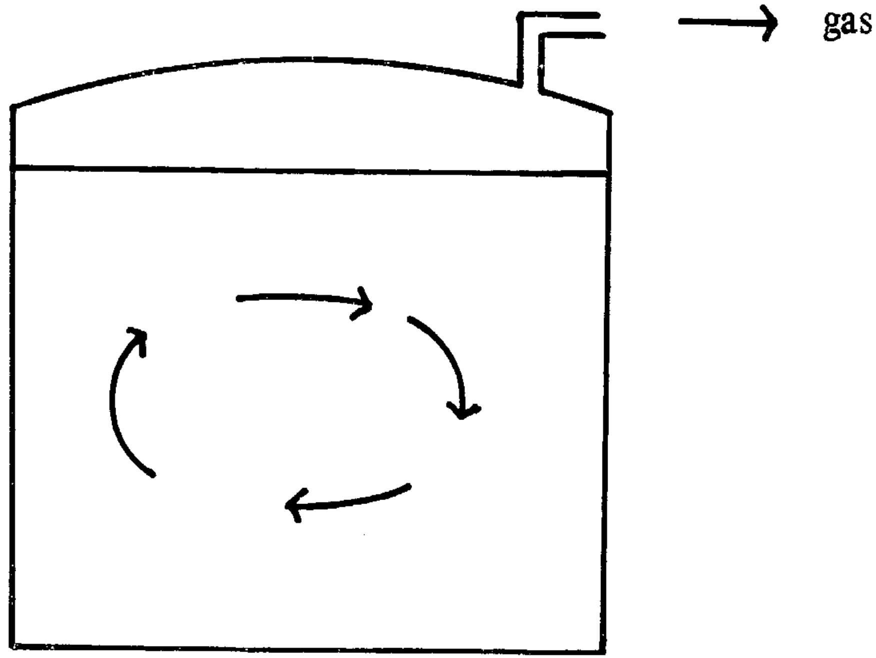

Fig. 2. Unheated, Mixed and Covered Digester.

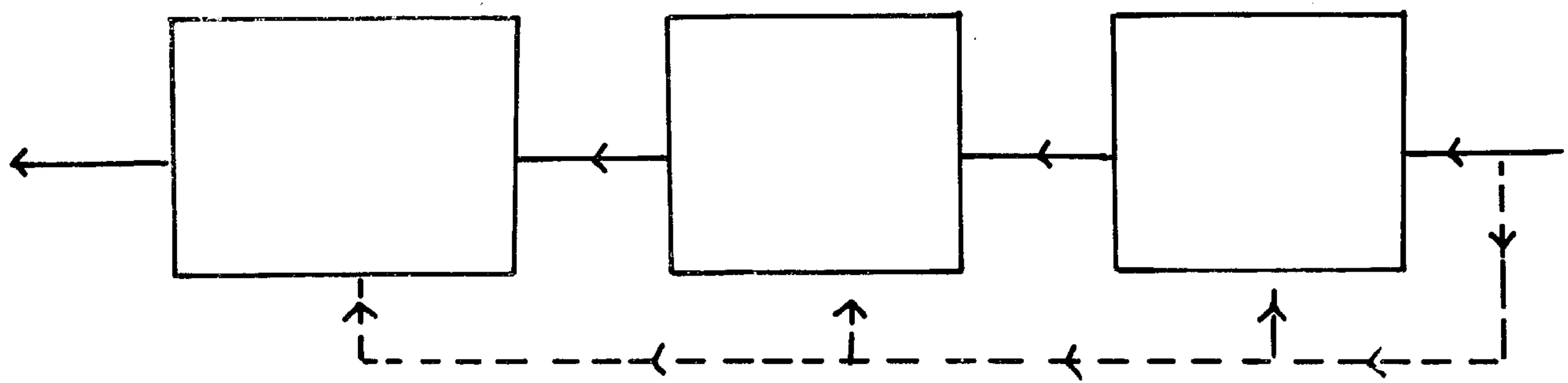

Fig. 3. Anaerobic Ponds

Table 1. Anaerobic Digester Loading Rates

Digester	Loading Rates		Retention Time
	Kg $BOD/m^3/d$	Kg $VS/m^3/d$	Days
Open-Top, Unheated and Unmixed	1.5	2.7	20
Covered, Unheated and Mixed	1.4	2.5	18
Anaerobic pond	0.4	0.4	30

There is close agreement between the two digesters and they are within the normally recommended figure of 3 Kg $VS/m^3/day$ that has been reported by *Cowley and Wase (1981)*. The operating temperature and retention time are 35°C and 15 days respectively. Such operating conditions should be easily attainable for palm oil mill operation. Also it is interesting to note that a waste of 95% water content is twice the volume of one of 90%. Hence by concentrating the POME (avoiding dilution wherever possible), the digester volume can be reduced accordingly. In the case of anaerobic pond, feed is very much diluted, as most of the solids have settled in the acidification ponds before the anaerobic ponds.

Digester Performance

All the digestion systems mentioned earlier gave promising results as shown in *Table 3.*

Table 3. Digester Performance

Digester	BOD reduction %
Open-top, Unheated and Unmixed	95
Covered, Unheated and Mixed	96
Anaerobic Pond	96

Remarkable BOD reduction was obtained in all cases. Such results are quite easily attainable if the digester is operated according to the following procedures:

i) Maintenance of frequent incremental feeding of raw effluent.

ii) Maintenance of frequent withdrawals of digested sludge.

iii) Minimization of the amount of diluting water within the raw effluent feed.

iv) Maintenance of the desired temperature throughout the digester tank volume.

v) Maintenance of a proper quantity of actively digesting seed material. This will be discussed later.

Starting up an Anaerobic Digester

With seed sludge

The best way to start a digester is by using seed sludge from a unit which already is operating satisfactorily. This will be an almost immediate start up if the operating temperature of the feed POME has been obtained. It is nevertheless important to note that the feeding should be increased slowly to the designed level, keeping proper checks on the digester conditions. (See Digester Control, Section 6).

Without seed sludge

The pH control process has been used successfully in the laboratory as well as in a commercial palm oil mill to restart a sour digester (in this case, an anaerobic pond). It is not necessary to empty the sour sludge in the digester or pond.

The following procedure is recommended:

i) For a new digester, fill the digester with water and maintain the pH between 6.4 – 7.4 by using lime, or bunch ash from the incinerator The use of caustic soda and ammonia were also reported.

ii) Lime or bunch ash is also added to neutralise the raw POME before it is fed into the digester. The feed should be increased slowly from about 10% of the design loading to full loading, depending on the conditions of the digester.

iii) If possible, recirculate the sludge daily.

iv) Keep a constant check on the pH at as many points as possible in the digester to ensure that a neutral pH of 6.5 – 7.5 is maintained. This can be easily checked by means of pH paper.

Causes of Digestion Failure

It is almost impossible to cite a single major cause for digestion failure. A review of the literature indicates the following possibilities.

a) Low pH

b) Low alkalinity

c) Overloading

d) High volatile acids

e) Toxic substances

f) Temperature changes

POME is non-toxic as it originates from vegetative matter, and no chemical is added in the oil extraction process. The properties of the effluent is also very consistent except for the oil content, which may vary quite a bit from mill to mill. The temperature of the feed can be maintained at the operating range i.e. ambient temperature quite easily by a holding pond for about one to two days. Hence, as far as POME is concerned the first four factors need close monitoring.

Digester Control

No process can be efficiently operated without having adequate control and an indication of its progress. In digester operation, controls are short-term and used for corrections. They are tests that can be run to confirm satisfactory operation or to indicate an action that would bring about change. Indicators are tests run, recorded and used for forecasting purposes.

Factors Affecting Anaerobic Digestion

Before we discuss digester control, it is important to know the factors affecting the digestion. Broadly speaking, there are five basic factors: bacteria, food, loading, contact (mixing) and environment.

Bacteria

The bacteria can only do their best when the right conditions are provided. The digesting and digested sludge contains all the necessary bacteria to stabilize the sludge. Thus, it is important to keep as much active sludge as possible in the digester, though a regular removal of some digested sludge is also necessary. This is determined by the digester performance and varies from plant to plant. The optimum level of active sludge in the digester for POME treatment has not been determined. A good guideline is to have about twenty times as much seed sludge as feed sludge expressed as volatile solids *(Zickefoose and Hayes, 1976)*.

Food

Volatile solids in the effluent are food for the bacteria. In raw POME about 80% of the total solids (about 5%) are volatile solids, the rest are inert or inorganic materials which cannot be digested, and has to be removed from the digester.

Loading

The following information are important in feeding the digester:

a) The solid concentration of the raw POME.

b) The amount of volatile solids in the feed which is about 80% of the total solids. This tells how much of the material can be used as food by the bacteria and indirectly the amount of undigestable substances.

c) The hydraulic loading (hydraulic retention time) which is related to the organism growth and washout.

Contact (Mixing)

Efficient digestion cannot occur unless the bacteria are brought into contact with the food. Mixing, therefore, will speed up the breakdown of volatile solids and increase gas production.

Only one agency's mills in the country employ mechanical mixing device, the rest of the mills depend on the gas produced for mixing. This provides an inexpensive method of mixing if the operation is closely controlled.

Environmental Factors Affecting Digestion

As mentioned earlier, the bacteria activity will slow down unless optimum conditions are maintained. The following conditions are cited in literature for optimum digestion.

i) Anaerobic conditions i.e. No oxygen (air)

ii) Temperature 29–37°C (Mesophilic)
48–57°C (Thermophilic)

iii) pH 6.8 – 7.2

Anaerobic conditions and temperature are the most important environmental factors affecting the activity of methane bacteria. No air is to be admitted into the digester. This may be the reason why mechanical stirring does not improve the performance of open-top digesters or anaerobic ponds. In fact it would be beneficial if a thin layer of scum could be maintained at the surface of the open-top digesters or ponds. For closed tank digesters the covers designed to collect the methane gas are used to keep air out.

Bacteria activity is very sensitive to temperature changes. As all the digestion for POME are operated at mesophilic range, (near ambient temperature) and there is no seasonal effect in Malaysia, there is very little fluctuation in the operating temperature of the system. The pH of the system undergoing anaerobic digestion is controlled by the amount of volatile acids produced and the alkalinity in the digester.

The production of volatile (organic) acids depends upon the amount of sludge (POME) fed to the digester. In a healthy digester system (both single-phase or two-phase), the acids produced will be consumed simultaneously by the methane bacteria. Under these conditions, the volatile acid content of the system usually falls below 1000 gm/l expressed as acetic acid. Apparently, the two-phase digestion system can tolerate a higher acid level. In any case, if the feeding is constant, a population balance between the two groups of bacteria will be maintained easily. However, if there is a sudden increase in feed, excess amount of acids would be produced and lower the pH. The methane formers cannot cope with the acids produced and acids accumulate in the digester. If the increase of acid level is not severe, the system can be kept under control by the buffering capacity of the digester. Buffering capacity is measured as alkalinity. During the digestion process, the methane formers also produce some buffering material, such as bicarbonates, carbonate and ammonia which goes into solution. This is usually enough to balance the excess acid produced occasionally so that the pH is maintained at constant level.

External Control

This involves monitoring of what is going into the digester and what is removed from the digester. Best operation can only be obtained if the properties of the feed material are kept as close to the designed values as possible. Sludge and grit should be removed at regular intervals to maintain constant effective digester volume.

Internal Control

Internal controls show what is happening inside the digester. Normally four tests are recommended for the best control: temperature, volatile acids, alkalinity and pH.

In Malaysia, as most of the digester treating POME operate at mesophilic range and there is little variation in ambient temperature, digester temperature is more or less constant. Hence, volatile acids, alkalinity and pH are the best control parameters. pH can be easily measured and volatile acids and alkalinity analyses are relatively simple and fast. However it is recommended that the three tests should be done simultaneously. pH alone does not show the actual conditions of the digester. Because of the alkalinity of the digester, the pH changes very slowly. In fact the digester may be completely upset before the pH changes. Perhaps the best control index is the volatile acids/alkalinity ratio. Though it varies from digester to digester the ratio should not be allowed to increase to more than 0.3 under any circumstance. An increase in the ratio is the first warning that trouble is starting in the digester. For a covered digester, gas production will also indicates the digester conditions. A decrease in gas production rate or an increase in CO_2 content in the gas signals digester trouble. Digesters respond very slowly once they are upset. Therefore, the best operation is obtained by preventing upsets. Prevention is better than cure. The following general guidelines are given for best process control:

i) Routine volatile acids and alkalinity determinations during any startup process are a must in bringing a digester to a state of satisfactory digestion.

ii) Measure the volatile acid/alkalinity ratio at least twice per week during normal operation, plot against time and watch for trends.

iii) Measure the volatile acid/alkalinity ratio at least daily when a digester is suspected of approaching trouble.

The following suggestions are given for corrective response when the volatile acid/alkalinity keeps rising.

i) Reduce feeding rate.

ii) Correct pH by adding lime, soda ash etc.

Conclusion

The key to successful operation is knowing the system and understanding the basic principles of the process. Though anaerobic digestion is used for POME treatment, a great majority of the operators lack the basic knowledge of digester operation and control. This article has provided some basic information in starting up a digester, factors effecting the digestion and how to use laboratory tests for process control. The operator, however, is cautioned against looking at the absolute number. The rate of change is much more important. The best and closest digester control is achieved by monitoring the process with more than one control parameter. The tightest control is obtained by monitoring the ratio between volatile acids and alkalinity. This method is the one which allows preventive control and is not too difficult to perform.

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