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High Rate Anaerobic Treatment of Industrial Wastewater in Tropics

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Abstract

The current common anaerobic treatment methods for industrial wastewater are presented. The advantages and disadvantages of aerobic versus anaerobic treatment are listed. The developments in high rate anaerobic reactors for the treatment of industrial wastewater are discussed. A new high rate anaerobic process, the reversing anaerobic upflow system (RAUS) is also introduced. RAUS, a new approach to anaerobic treatment is compared with other processes like fixed bed and UASB reactors. The results of experiments conducted on anaerobic treatment of various industrial wastewaters are presented. The importance of anaerobic treatment in a tropical country like Thailand has been highlighted.

Introduction

Rapid industrialization in Thailand has tremendously increased the volume of wastewater to be disposed of, while the capacity of receiving water to accept the increasing inorganic and organic loads remains the same. This has resulted in a rapid deterioration of quality of surface water, especially in and around Bangkok and at the same time stimulated concerned government agencies to introduce and enforce more stringent legislation. Forced by the legislation, industries are looking for the least cost solutions for the required reduction of pollution load.

The aerobic treatment processes were very predominant in biological treatment of wastewater up to the seventies. The aerobic treatment systems require energy for the transformation of oxygen to degrade the waste. As a result of environmental debate and the increase in energy prices in the eighties, this picture changed significantly. Reuse and recycle of waste and the conservation of energy has become the current topic of interest and the anaerobic process that produces energy in the form of biogas has now emerged with a new potential.

In the light of rising energy prices, the potential of energy production and reduction of energy consumption by anaerobic treatment of industrial wastewater should not be overlooked, especially in a tropical country like Thailand, where the relatively high ambient temperature is close to the optimum for the mesophilic methanogenic bacteria.

Treatment of Industrial Wastewater

The total treatment system of industrial wastewater varies depending upon the type of industry. Industrial wastewater can include floating matter, sand and grit, oil and grease, organic matter, toxic elements and various chemicals.

Considering experience with treatment plants operating in Thailand four types of treatment can be distinguished.

- mechanical treatment
- physico-chemical treatment
- aerobic biological treatment
- anaerobic biological treatment

The mechanical treatment methods are commonly used for the removal of floating matter, sand and grits and the settleable matters.

The physico-chemical treatment involves processes requiring substantial quantities of chemicals and skilled labor.

The aerobic biological treatment methods are extensively used in Thailand for the treatment of industrial wastewater. In aerobic treatment, micro-organisms that need oxygen are used to convert the wastewater compounds into harmless components. The most commonly used aerobic treatment processes are oxidation pond, activated sludge, trickling filter, aerated lagoon and a combination of these.

Anaerobic Biological Treatment

In the anaerobic treatment of wastewater, the energy is extracted from the waste components without the introduction of air or oxygen. The anaerobic treatment of wastewater has now emerged as an energy saving wastewater treatment technology. It has been used worldwide for a wide spectrum of industrial wastewater since the development of high rate anaerobic processes. Due to increasing energy cost in aerobic wastewater treatments, the technique of anaerobic wastewater treatment has gained substantial importance.

Anaerobic treatment involves biological processes that take place in the absence of oxygen and in which the organic materials are degraded to produce biogas. The biogas produced may be commercially exploited.

The anaerobic degradation of organics can be divided into four steps:

1. Hydrolysis: Proteins, fats and polymers are converted into monomers by enzymes and microorganisms.

2. Acidification: Amino acids and sugars are fermented into alcohols, volatile fatty acids and carbon dioxide.

3. Acetogenesis: Anaerobic oxidation of fatty acids and alcohols into acetic acid and hydrogen.

4. Methanogenesis: Formation of methane gas from acetic acids, carbon dioxide and hydrogen.

High Rate Anaerobic Reactors

Anaerobic reactors are categorized by the achievable organic loading rate expressed as kg COD/(m^3.d).

Sludge digesters, septic tanks, inhoff tanks and anaerobic ponds are examples of low rate systems. In these systems the ratio of solid retention time (SRT) and the hydraulic retention time (HRT) has a low value, close to 1.0, which is of limited value in the treatment of liquid industrial wastewater. In a reactor with SRT/HRT ratio close to 1, 'washout' of anaerobic microorganism will pose a serious problem if high loading rates are applied. Hence, developments in anaerobic processes for industrial wastewater treatment have concentrated on ways of achieving high SRT/HRT ratios, thus allowing high loading rates to be applied to small reactor volumes. Among the high rate systems, that are applied in practice are the anaerobic contact process, the anaerobic fixed bed (FB) reactor and the upflow anaerobic sludge blanket (UASB) reactor.

Anaerobic Contact Process

In this process (Fig. 1), the reactor effluent is pumped to a settling unit from where a portion of the settled sludge is recycled to the reactor enabling the contact unit to maintain a high concentration of active biomass [1].

Fixed Bed (FB) Reactor

Another way of increasing the solid retention time for methane producing bacteria with short hydraulic retention time for system economy is by using a fixed film reactor (Fig. 2). In these systems, the microorganisms grow in the film in a solid support while organic matter is removed from the liquid flowing past them. The upflow filter [2], fluidized bed reactor and the downflow fixed bed reactor [3] all belong to this category.

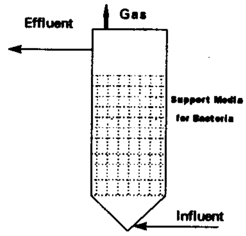

Fig. 2 Fixed bed Upflow System

Upflow Anaerobic Sludge Blanket (UASB) Reactor

The UASB reactor (Fig. 3) was first developed by Lettinga [4] in the Netherlands. The essential feature of this reactor is the presence of very active biomass in the bottom of the reactor. The UASB reactor operates entirely as a suspended growth system and uses no packing material. The microbes attach themselves to each other or small particle of suspended matter to form granules that have excellent settling properties.

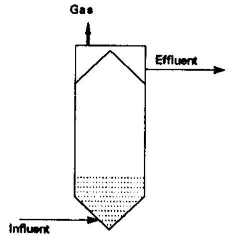

Fig. 3. The UASB System

Reversing Anaerobic Upflow System (RAUS)

In principle, the reversing anaerobic upflow system (RAUS) is slightly similar to UASB system. But it consists of two anaerobic reactors interconnected with one another (Fig. 4). When one reactor is fed upward with wastewater, the other one acts as the settler. After a certain set period of time, the flow is reversed such that the second reactor is fed with wastewater and the first one now acts as the settler.

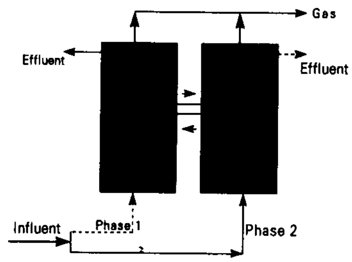

Fig. 4. The RAUS System

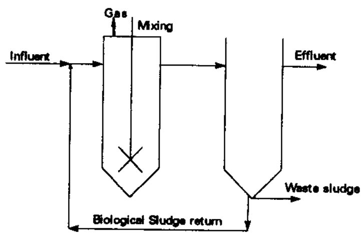

Fig.1 Anaerobic Contact System

The research carried out by the authors with various industrial wastewaters revealed that through intermittent feeding pattern and flow reversion in RAUS, a significant improvement of sludge quality was achieved with distillery wastewater [5] and polyester fiber wastewater [6] treatment.

Apart from better sludge quality, lower construction cost seems to be one of the advantages of RAUS over fixed bed, UASB and other reactor types. No separate settler with sludge return pump is required as in the anaerobic contact process. There is no loss of reactor volume through filter material as in the case of fixed bed reactor. There is no need for high rate effluent recirculation as in the case of fluidized bed reactor.

Materials and Methods

The research on anaerobic treatment was carried out using laboratory scale reactors as well as pilot scale reactors of different volumes ranging from 10.2 liters (small-scale acrylic reactor) to 3400 liters (pilot-scale steel reactor). The research was done at AIT ambient laboratory as well as on site at the respective factory location.

Wastewater from four different industries was used for the research namely, polyester fiber factory, distillery, slaughter house and pineapple canning factory.

Various types of highrate anaerobic reactors were used such as fixed bed reactor, UASB reactor and RAUS reactor.

Results and Discussions

Organic Loading Rate (OLR) and Hydraulic Retention Time (HRT) Achieved with RAUS

RAUS was investigated using several types of wastewater, with low strength wastewater such as from the slaughter house to high strength wastewater from the distillery. The maximum achievable organic loading rate (OLR) and respective hydraulic retention time (HRT) are listed in Table 1.

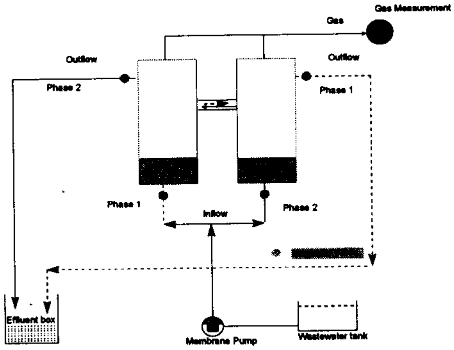

Fig. 5.Schematic Diagram of Experimental Setup for RAUS

The COD removal efficiency was independent of the reactor type (Table 2) although the achievable OLR was different for different reactor types. Fixed bed reactor (FB) was easier to start up and the loading could be increased faster in this type of reactor compared to other types.

Table 1 Maximum Achievable Stable OLR in RAUS

Wastewater	COD Range (g/l)	OLR (kgCOD/m^3.d)	HRT (days)	COD removal (%)
Slaughter-house	0.2 - 0.8	1.0	0.40	52
Pineapple canning	3.0 - 8.0	9.0	0.9	90
Polyester	15 - 30	4.5	6.0	88
Distillery	55- 70	7.0	8.0	52

AIT: Asian Institute of Technology;
COD: Chemical Oxygen Demand

Table 2. Comparison of RAUS with Other Reactors in Treatment of Various Wastewater

	Polyester fiber			Distillery			Slaughter house		
	UASB	RAUS	FB	UASB	RAUS	FB	UASB	RAUS	FB
COD removal (%)	88	88	88	52	52	52	--	55	55
OLR (kgCOD/m^3.d)	2.5	4.5	2.5	4.0	7.0	8.0	--	1.0	1.0
Methane Content in biogas (%)	77	77	75	60	64	61	--	74	71
Feed pattern	cont.	int.	cont	cont.	int.	cont.	--	int.	cont.

cont.: Continuous; int.: intermittent

Table 3. Average Sludge Washout in Different Reactor Types (g/l)
(Wastewater: Polyester fiber)

Operation Period (days)	OLR (kg COD/m^3.d)	Fixed Bed	UASB	RAUS
Day 1 - Day 50	0.5	0.38	1.4	0.6
Day 51 - Day 90	1.0	0.39	3.4	1.7
Day 91- Day 180	3.0	0.40	24.0	3.0

Suspended Solids Washout and Sludge Quality

Due to its intermittent feeding pattern and reversion of flow in RAUS, the reactor could retain more suspended solids (Table 3) thus improving the sludge enrichment inside the reactor and therefore improving the sludge characteristics in terms of methanogenic activity and granulation.

Advantages and Disadvantages of Anaerobic Treatment

In making a selection from the great variety of biological treatment systems, a number of aspects should be considered.

The Effluent Quality Required

The efficiency of anaerobic reactor is relatively lower , generally less than 80 % and therefore post treatment of effluent is normally required. For aerobic systems the efficiency varies between 90 to 98 % depending upon the type of reactor and loading.

Energy Consumption

The energy demand for anaerobic treatment is generally much lower. Sometimes an energy surplus is generated by the production of biogas from anaerobic reactor.

Energy is required to obtain a high quality effluent. Treatment of high strength wastewater by aerobic process requires a very high energy demand.

Operation and Sensitivity

Simplicity of operation and maintenance is an important criterion. Anaerobic reactors are more susceptible to upsets, variation of flow and shock loading than aerobic reactors . Although anaerobic reactors are simpler in operation they need close monitoring.

Land use

In areas where land is scarce, compact plants will be preferred. Anaerobic reactors are more compact due to higher design organic loading rates.

Sludge Production

Anaerobic treatment of wastewater can reduce the amount of secondary sludge that is troublesome to dispose of.

Nutrients Requirement

Anaerobic treatment process requires less nutrients in wastewater for biomass growth thus saving the cost.

The pros and contras of anaerobic process compared with aerobic process are summarized in Table 4.

Table 4. Pros and Contras of Aerobic and Anaerobic processes

	Aerobic	Anaerobic
Energy consumption	-	+
Excess sludge production	-	+
Sludge loading	-	+
Effluent quality	+	-
Nutrients requirement	-	+
Sensitivity	+	-
Land use	-	+

+ : advantage; - : disadvantage

Balancing the pros and contras described above, there has been ample reason during recent years for many industries in the world to install an anaerobic treatment system as the pre-treatment step. Such a system reduces the wastewater burden on the secondary aerobic treatment systems and also recycles some of the energy value of waste back into the manufacturing process.

Importance of Anaerobic Treatment in Thailand

The optimum temperature level for mesophilic anaerobic treatment is recognized as being in the range of 30 to 34° C. The mesophilic range has generally been found to be the optimum temperature for most industrial wastewaters, primarily because of the dilute nature and low suspended solids content of the wastes [7]. In a tropical country, the ambient temperature is relatively high and close to the optimum range for the mesophilic methanogenic bacteria. Therefore there is no doubt that the anaerobic treatment system should be considered as a first stage organic removal, for the treatment of strong organic industrial wastewater in a tropical country like Thailand.

A range of anaerobic processes is available and selection will depend upon the type of waste, the availability of land, the economic situation of the industry and the availability of skilled technical staff. The final choice should only be made after carrying out pilot plant studies on the wastewater and consideration of treatment objectives and costs. The authors have found the following advantages of an onsite pilot-scale reactor at the factory location:

a. It takes into account the actual conditions for the development of more reliable design criteria for full-scale plant.

b. It helps in better understanding of the wastewater flow from the factory.

c. It gives an opportunity to train the factory personnel about the operation of wastewater treatment plants.

Based upon the research on anaerobic treatment of various industrial wastewater, the following achievements are already possible or foreseen.

1. In Thailand, twelve distilleries have their own full-scale anaerobic (UASB) treatment plants (volume = 3000 m^3). After the successful startup of one of the UASB reactors in Buri Ram, supported by pilot scale research [8], other distilleries have also successfully started up their plants and have been operating with success.

In each distillery an estimated amount of about 15,000 kg COD/d has been eliminated by anaerobic treatment. In return an estimated amount of over 1.2 million m^3 of methane gas is produced per year, which can replace annually around 0.75 million liters of fuel oil in the factory operation.

2. At the polyester factory, the following achievements can be estimated if a full-scale anaerobic treatment plant is constructed.

Sludge production and disposal can be reduced by 60 percent. Energy demand for aerobic treatment can be reduced by 3,000 kwh/d. Production of bio gas amounts to 600 m^3/d. Nutrient addition to wastewater can be reduced by 60 percent.

3. Anaerobic pilot-scale experiments conducted at a pineapple canning factory showed that loading up to 9 $kg/(m^3/d)$ could be possible with RAUS reactor. An average gas production of around 5,000 m^3/d can be acheived from its wastewater [9].

Conclusions

Anaerobic treatment is presently the lowest cost wastewater treatment option for highly polluted industrial wastewater in a tropical country like Thailand. Some time may be still needed for the introduction of this technology. Experience has to be transferred and strengthening the development of more appropriate training techniques is urgently required.

RAUS is a new approach to anaerobic treatment of industrial wastewater and it needs further investigation. The principle of intermittent feeding and flow reversion used in this system has shown improvement in sludge characteristics as well as in the reactor performance.

If no experience is available on the treatability of a specific wastewater, it is advisable to simulate the process in a laboratory and if possible to carry out 'onsite' research at the factory site.

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