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THESIS

H_2S REMOVAL IN FULL SCALE BIOTRICKLING FILTER WITH UASB EFFLUENT

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A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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Biogas from UASB system contains a small percentage of H_2S which must be removed before the biogas can be utilized in electricity generation. H_2S removal by biological process is successful in laboratories and in full scale reactors. This study investigated startup, performance, and recovery time of a full scale biotrickling filter in removing H_2S from biogas. The biogas was obtained from UASB system treating wastewater from a starch production plant. The 3.5-m diameter and 8-m high reactor was packed with 70 m^3 plastic media. Biogas with 1,000 to 3,000 ppm H_2S was mixed with air and was upwardly fed into the column at 400-850 m^3/hr. UASB effluent was sprayed on top and trickled down the column at 20 m^3/hr Start up time of the system was 3-4 days, achieving 86.3 percent H_2S removal. Loss of O_2 resulted in the decrease in removal percentage. The system could resist a short period (less than 10 hours) moisture loss. Performance failure of the system due to 1, 2 and 15 days complete shut down could be recovered within 4-5 days.

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Student's signature Thesis Advisor's signature

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Nittiya Ngaonee

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LIST OF ABBREVIATION

BOD	=	Biochemical Oxygen Demand
COD	=	Chemical Oxygen Demand
Eff	=	Effluent
H_2S	=	Hydrogen sulfide
Inf	=	Influent
L	=	Liter
L/h	=	Liter/Hour
mg/L	=	Milligram/Liter
min	=	Minute
O_2	=	Oxygen
ppm	=	Part per million
S^0	=	Element sulfur
S^{2-}	=	Sulfide
SO_3^{2-}	=	Sulfite
SO_4^{2-}	=	Sulfate
T.denitrificans	=	*Thiobacillus denitrificans*
T.thioparus	=	*Thiobacillus thioparus*
UASB	=	Upflow Anaerobic Sludge Blanket
VFA	=	Volatile Fatty Acid
EBRT	=	Empty Bed Retention time
OSHA	=	Occupational Safety and Health Administration

H_2S REMOVAL IN FULL SCALE BIOTRICKLING FILTER WITH UASB EFFLUENT

INTRODUCTION

Hydrogen sulfide (H_2S) is a product of anaerobic oxidation. It causes health and environmental problems. Contamination of H_2S in biogas also reduces energy value and causes corrosion of metal parts of equipment used. It is commonly removed by chemical or physico-chemical methods. The disadvantages of these methods include handling and storage of chemicals and treatment of reaction products. H_2S removal can also be achieved by biological process with H_2S utilizing bacteria such as *Thiobacillus* species. *Thiobacillus* species can be found in various environments such as soil and wastewater. Biological process is inexpensive and have less impact on the environment. Biological treatment system commonly used for gas treatment include biofilters, biotrickling filters and bioscrubbers (Bergess et al., 2001; Elias et al., 2002). These systems differ in the presence or absence of a carrier material, the phase of the biomass (suspended or fixed), and the state of the liquid phase (flowing or stationary)

Biotrickling filters for air pollution control are bioreactors in which the contaminated air stream is passed through a packed bed on which pollutant degrading organisms are immobilized as biofilms. The organisms degrade absorbed contaminants to harmless compounds (Devinny et al., 1999). Biotrickling filters have been shown to work well for the control of hydrogen sulfide, reduced sulfur compounds (RSC), and VOC, either as sole pollutants or as complex gas mixtures (Yang et al., 1994; Smet et al., 1998; Fortin et al., 1999). In the case of hydrogen sulfide control, autotrophic organisms oxidize sulfide to sulfate by using carbon dioxide as carbon source. Carbon dioxide will transport an electron to oxygen in the presence of oxygen and will transport an electron to nitrate in the absence of oxygen,

the final product is sulfur. For volatile organic (VOC) treatment, heterotrophic organisms utilize VOC as an energy sources.

Upflow anaerobic sludge blanket (UASB) is an important biogas production process and effluent from the process is found to contain *Thiobacillus* species. Removal of H_2S by biotrickling filter process with the presence of *Thiobacillus* and the use of UASB effluent to provide nutrient and moisture was successful in lab scale reactor (Kim et al., 2000; Potivichayanon et al., 2005; Ramirez, et al., 2009; Gabriel et al., 2003; Kazuhiro et al., 1995; Suwanvitaya and Doungprasopsuk., 2010; Wongudom., 2008). BTF is also employed in full scall. The problem frequently encountered include interruption of air and water supplies due to maintenance procedures or power shortage. When these happen, microbial activities are interrupted resulting in system failure to remove H_2S. The system need to be restarted or recovered. Understanding the effects of causes of system shut down will be a benefit to operating the system.

Hydrogen sulfide is currently removed using, physical, chemical and biological practices. The physicochemical processes have high operating costs and also produce chemical waste by-products that must be disposed of before discharge. Recently, the chemobiological processes are used for the gas treatment (Park et al., 2005; Son et al., 2005). However these processes still use the chemical reagent and have acidic condition for the oxidation reaction which has some cost of the operation. For these reason, biological processes are more attractive because they are inexpensive and cause no environmental pollution.

In this study, experiment on H_2S removal from contaminated biogas was carried out in a full scale biotrickling filter packed with plastic media. Biogas containing UASB process was upwardly fed into the column, UASB effluent sprayed counter-currently to provide bacterial culture and moisture. The effects of variations in the flows of H_2S gas and UASB effluent on removal efficiency was then determined.

OBJECTIVES

In this study full scale biotrickling filter was used to determine the following.

1. Time for system start up.
2. The effects of O_2 shut off and moisture shut off on H_2S removal in full scale biotrickling filter
3. Time for system recovery from system failure due to interrupted flow of H_2S, air and UASB effluent.

Scope of This study

1. Biotrickling filter column used in the study was constructed from fiberglass reinforced plastic (FRP) shells, with 3.5 m. inner diameter and 8 m. height. Plastic media were packed in the column to the height of 3.50 m.
2. Gas output from UASB process of starch production (Soidao District, Chanthaburi Province) was used as the sample contaminated with H_2S. H_2S concentration in the air sample was in the range of 1000-3000 ppm.
3. UASB effluent from UASB process of starch production (Soidao District, Chanthaburi Province) was collected and stored in the pond for the use in biotrickling filter column. It provided starter culture and moisture to the system under study.
4. H_2S was mixed with air and pumped upwardly through a packed column at various flow rates. UASB effluent was sprayed onto the packing media.

LITERATURE REVIEW

1. Biological wastewater treatment options

Biological treatment processes can be categorized into 2 types: Aerobic process and anaerobic process. Aerobic biological process is the process which bacteria utilize organic compounds into CO_2 and H_2O using oxygen as an electron acceptor, for example activated sludge, fixed film tricking filter, etc. Anaerobic biological process is the process which bacteria utilize organic compounds into CO_2, CH_4 and H_2O, by the use of other compound as an electron acceptor, for example anaerobic digester, anaerobic filter, UASB, etc.

2. UASB (Upflow Anaerobic Sludge Blanket)

Upflow anaerobic sludge blanket (UASB) is an anaerobic process, in which a blanket of granular sludge is formed and suspends in the tank. Wastewater flows upwards through the blanket and is processed (degraded) by anaerobic microorganisms. The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants.

UASB is an important biogas production process. It is an anaerobic biotechnology system consisting of many species of acid bacteria and methane-forming bacteria living together and decomposing organic matter resulting in biogas production. Figure 1 shows surveying result done by Hulshofpol (1998). It was found that 70% of all anaerobic system nowadays is UASB system. This is because of its high efficiency.

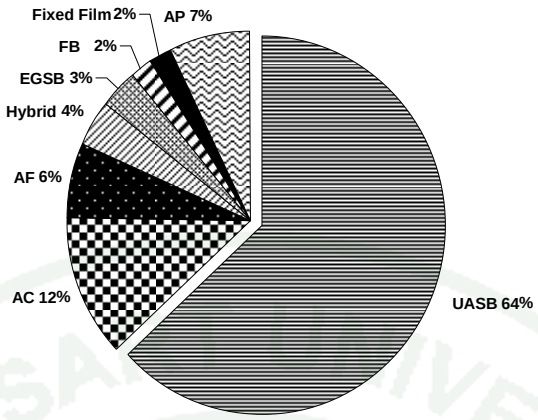

Figure 1 Ratio of Anaerobic Process

Source: Hulshofpol (1998)

3. Biogas Production

Biogas is a mixture of methane (CH_4) and carbon dioxide (CO_2) and is often contaminated with toxic quantities of hydrogen sulfide (H_2S). Biogas with a high concentration of methane may be used as an energy source, to generate electricity for export and to cover its own running power. The technology needs constant monitoring when put into use to ensure that the sludge blanket is maintained, and not washed out (thereby losing the effect).

3.1 Quantity and characteristics of biogas

- Quantity of biogas depends on quantity of biological degradable organic matter in slop wastewater (in terms of COD, BOD)
- Biogas production rate is 450 – 500 liters/kg COD removed
- Characteristics of biogas depend on characteristics of slop and technologies applied for biogas production. They can be varied in a wide range as followed:

CH_4	55 – 65	%
CO_2	35 – 45	%
H_2S	0 – 3	%

Small amount of N_2 and moisture

3.2 Quality Requirements for Biogas

Biogas can be used for all applications designed for natural gas, assuming sufficient purification. On-site, stationary biogas applications generally have fewer gas processing requirements. A summary of potential biogas utilization technologies and gas processing requirements are shown in Table 1

Table 1 Biogas utilization technologies and gas processing requirements

Technology	**Recommended Gas Processing Requirements**
Heating Boilers[1]	H_2S < 1000 ppm, 0.8-2.5 kPa pressure, remove condensate (Kitchen stoves: H_2S < 10 ppm)
Internal Combustion Engines[1]	H_2S < 100 ppm, 0.8-2.5 kPa pressure, remove condensate, remove siloxanes (Otto cycle engines more susceptible to H_2S than diesel engines)
microturbines[2]	H_2S tolerant to 70,000 ppm, >350 BTU/sef,520 kPa pressure, remove condensate, remove siloxanes
Fuel Cells[3]	PEM: CO<10 ppm, remove H_2S PAFC: H_2S < 20 ppm, CO<10 ppm, Halogens< 4 ppm MCFC: H_2S < 10 ppm in fuel (H_2S < 0.5 ppm to stack), Halogens< 1 ppm SOFC: H_2S < 1 ppm, Halogens< 1 ppm
Stirling Engines[4]	Similar to boilers for H_2S < 1-14 kPa pressure
Natural Gas Upgrade[1,5]	H_2S < 4 ppm, CH_4<95%, CO_2 < 2 % volume, H_2O<($1x10^{-4}$) kg/MMscf, remove siloxanes and particulates, > 3000 kPa pressure

Sources:

[1] Wellinger and Linberg (2000)

[2] Capstone Turtine Corp (2002)

[3] XENERGY (2002)

[4] STM Power (2002)

[5] Kohl and Neilsen (1997)

Technologies such as boilers and sterling engines have the least stringent gas processing requirements because of their external combustion configurations. Internal combustion engines and micro turbines are the next most tolerant to contaminants. Fuel cells are generally less tolerant to contaminants due to the potential for catalytic poisoning. Upgrading to natural-gas quality usually requires expensive and complex processing and must be done when injection into a natural-gas pipeline or production of vehicle fuel is desired (Zicari, 2003).

4. Hydrogen sulfide (H_2S)

Hydrogen sulfide (or hydrogen sulphide) is the chemical compound with the formula H_2S. H_2S is produced naturally during the reduction of sulfate and sulfur-containing organic compounds by nonspecific anaerobic bacteria (Hesketh et al., 1989). It often results from the bacterial breakdown of organic matter in the absence of oxygen, such as in swamps and sewers (anaerobic digestion). It also occurs in volcanic gases, natural gas, and some well waters. The human body produces small amounts of H_2S. Hydrogen sulfide (H_2S) is also emitted by many industrial activities such as petroleum refining, natural gas and petrochemical plants, craft pulp manufacturing, viscose rayon manufacturing, food processing, tanneries, aerobic and anaerobic wastewater treatments.

H_2S is colorless gas with characteristic odors of rotten eggs, noticeable at concentration as low as 0.5 ppm. (Busca et al., 2003). H_2S is heavier than air. It is flammable, highly corrosive and toxic to human. Effects of H_2S on human depend on exposure concentration and time (Roth 1993). Upon inhalation, hydrogen sulfide reacts with enzymes in the bloodstream and inhibits cellular respiration resulting in pulmonary paralysis, sudden collapse, and death. Continuous exposure to low concentrations (15-50 ppm) will generally cause irritation to mucous membranes and may also cause headaches, dizziness, and nausea. Higher concentrations (200-300 ppm) may result in respiratory arrest leading to coma and unconsciousness. Exposures for more than 30 minutes at concentrations greater than 700 ppm have been fatal

(MSDS, 1996). A ceiling concentration of 20 ppm at the workplace with a maximum concentration of 50 ppm for no more than 10 min has been recommended by the US Occupational Safety and Health Administration (Busca et al., 2003).

H_2S is heavier than air. Its value of Henry's Law constant for the air-water-H_2S system at 25ºC is 0.41 (H_2S concentration in air/H_2S concentration in water). Usually H_2S is found in mixture with other organic sulfur compounds such as methanethiol, dimethylsulfide and dimethyldisulfide. This mixture is known as the Total Reduced Sulfur Compounds (TRS). (Ruokojarvi et al., 2000).

Table 2 H_2S exposure condition recommended by OSHA.

Condition	**Volume**
Molecular Weight	34.08
Specific Gravity (relative to air)	1.192
Auto Ignition Temperature	250'C
Explosive Range in Air	4.5 to 45.5 %
Odor Threshold	0.47 ppb
8-hour time weighted average (TWA) (OSHA)	10 ppm
15-minute short term exposure limit (STEL) (OSHA)	15 ppm
Immediately Dangerous to Life of Health (IDLH) (OSHA)	300 ppm

Source: OSHA (2002), www.OSHA.gov

5. Biogas purification method

Need for H_2S removal can be found in various sectors. The most common is H_2S removal from biogas. Removal methods normally employed include physical, chemical and biological practices. The physicochemical processes have high operating costs and also produce chemical waste by-products that must be disposed of

before discharge. Recently, the chemo biological processes are used for the gas treatment (Park et al., 2005; Son et al., 2005). However, these processes still use the chemical reagent and have acidic condition for the oxidation reaction adding cost to the operation. For these reason, biological processes are more attractive because they are inexpensive and cause no environmental pollution. The major systems commonly used are biofilters, biotrickling filters and bioscrubbers (Bergess et al., 2001; Elias et al., 2002). These systems differ in the presence or absence of a carrier material, the phase of the biomass (suspended or fixed), and the state of the liquid phase (flowing or stationary).

6. Biotrickling Filters

In biotrickling filters, the polluted air is passed through a packed column where liquid is continuously re-circulated through the packing. Figure 2 shows generalized diagram of biotrickling filter. The pollutant is first solubilized in the falling liquid film, and then transferred to the microorganisms growing on the surface of the supports. The liquid provides moisture, nutrients, pH control to the biofilm, and allows the removal of inhibiting products. Ideally, the excess biomass is sloughed off by the trickling liquid, and a stable operation can be achieved.

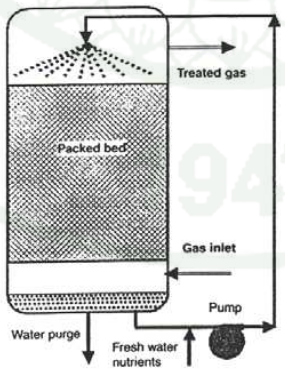

Figure 2 Schematic diagram of a biotrickling filter

Source: Shareefdeen (2005)

The supports are inert random or structured packings that are similar to those used in traditional scrubbers (plastic Raschig or Pall rings and saddles), although others such as lava rock or polyurethane foam have been tested. The air may be directed upflow or downflow, which is countercurrent or co-current with the liquid flow, respectively. It has been shown that generally there is no difference, except when there is stripping from the incoming liquid in the countercurrent configuration. To maintain low pressure drop and reduce clogging, the supports have low porosity and low specific surface (100-400 m^2/m^3). Empty bed retention time (EBRT) are normally around 30 s but systems with EBRTs as low as 1.2 s have been reported for low H_2S concentration (Gabriel and Deshusses, 2003).

Overgrowth causes an increase in pressure drop, reduced real residence time, and a drop in performance. Several strategies have been studied to control overgrowth while maintaining appropriate microbial activity. These include choosing a specific size and structure for the packing, limiting organic load, limiting nutrients, and adding inhibitors (Diks and Ottengraff, 1994). The possibility of using microbial predators, such as protozoa and nematodes (Cox and Deshusses, 1999), has been reported. In extreme cases the reactor has to be shut down and cleaned.

6.1 Factors Affecting Biofilter Performance

6.1.1 Packing Media

To maximize the biodegradation of airborne contaminants, several factors can be optimized, many of which focus on the packing media. Many biofiltration companies have proprietary media that are designed to provide optimal performance through the use of high surface for biofilm growth, long-term physical stability, low pressure drop, good moisture retention, pH buffering capacity, and nutrients. Traditional natural medium components that are frequently used for simple biofilters include compost, peat, wood chips, fertilizer, and soil. Some biofilters are also packed with adsorbents such as activated carbon, Although these adsorbents can

be helpful in that they can reduce the quantity of contaminant that escapes during the microbiological acclimation period (Bishop and Govind, 1995), and have potential to damper peak loads if the adsorbent is not coated with a deep biofilm, they do not improve performance during steady-state operation (Mohseni et al., 1998).

6.1.2 Moisture Content

Moisture content of the filter bed is a critical factor for biofilter effectiveness, because microorganisms require water to carry out their normal metabolic activities (Ottencgraf, 1986; Shimko et al., 1998; Marsh, 1994). Too low a moisture content causes drying of the bed, along with the development of bed fissures short circuiting air flow. This also deprives microorganisms of water, causing a significant reduction in the biodegradation rate. Too much water inhibits transfer of oxygen and hydrophobic pollutants to the biofilm, thereby promoting the development of anaerobic zones within the bed and limiting the reaction rate. Too much water can also result in foul smelling emissions due to the lack of oxygen, increasing backpressure due to the reduced void volume, and channeling of the gas within the bed. Optimal water levels vary with different filter media, depending on medium surface area, porosity, and other factors (Hodge et al., 1991). Filter moisture content for optimal operation of the biological filter should be within 30-60% by weight, depending on the medium used (Ottengraf, 1986, 1987; van Lith et al., 1990).

Moisture levels in a biofilter are often maintained through prehumidification of the inlet gas stream. Also, it is often necessary to provide direct application of water to the bed through a sprinkler system at the top of the bed. More advanced controls include the use of load cells that sense the weight of filter bed (van Lith et al., 1990; Rozich, 1995) and are connected to sprinkler controls. Supplemental moisture adjustments may be required because bio-oxidation is an exothermic reaction, and drying can occur within the bed. Drying of the packing material can lead to localized dry spots, and can result in non-uniform gas distribution and reduction in the activity of microorganisms.

From the perspective of adding moisture, it is often advantageous to have the flow of waste gas downward (van Lith et al., 1990). Since most of the drying occurs at the entrance to the filter bed, drying at the top is easily handled through direct water addition and flow from the top to the bottom. Downward flow also helps when too much water is added (either directly or due to humid gas cooling), since the water will flow by gravity co-currently with the gas out the bottom of the filter.

6.1.3 Temperature

Temperature control is also very important in biotrickling filter to avoid thermal shocks. There are three general temperature classes of aerobics microorganisms: psychrophilic microorganisms, which grow best below a temperature of 20 °C; mesophilic microorganisms, which achieve highest growth rates at 20-40 °C; and thermophilic organisms, which grow best above 45 °C. Biological activity roughly doubles for each 10 °C (Leson and winter, 1991; Vohn, 1992). This means that if the pollutant gas temperature is above 40 °C, then the gas should be cooled before it enters the biotrickling filter, similarly, for cold air below 10 °C, the heating of the gas stream to a desirable temperature is needed because microorganisms are relatively inactive at low temperatures. The cost of controlling temperature to within the mesophilic range often means that it is not economical to treat emissions that are relatively cold or hot. However, some recent studies suggested that we may be able to expand the temperature range of biotrickling filter, and treat emissions at the temperature at which they are emitted. For example, Giggery et al. (1994) reported on the biotrickling filter of odor below 0 °C with snowfall. Also, a recent study by Kong et al. (2001) has shown that treatment of methanol and α-pinene can be conducted at temperatures up to 70 °C, and Datta et al. (2004) have shown that hydrogen sulfide can also be effectively treated at 70 °C. Future work at the laboratory, pilot and full scale in expanding the temperature range can open the economic application of biotrickling filter to a range of emission sources.

6.1.4 Oxygen Content

Oxygen is vital to the operation of biotrickling filter because the predominant microorganisms used in biotrickling filter are aerobic, and require oxygen for metabolism. Aerobic heterotrophic bacteria present in filter beds require at least 5 - 15% oxygen at the inlet gas stream to survive (Dharmavaram, 1991). Yang et al. (2002) stated that biofiltration can be oxygen-limited in highly loaded systems, biofiltration with 63 % oxygen in the inlet stream increased the maximum removal rate of methanol from 120 to 145 g/m^3.h over regular air (21 % oxygen); a further increase in oxygen content up to 80 % did not lead to a further improvement in biofilter performance. Generally, for most air pollution control systems, oxygen supply is not an issue because it is abundant in the incoming airstream and the biofilm is relatively thin. In overloaded filters, however, it may be a limitation resulting in the formation of acidic and other intermediates.

6.1.5 pH

Microorganisms have a specific, optimum pH range for their activities. The pH within the biotrickling filter can be maintained by the addition of solid buffer agents to the packing material at the beginning of the operation, and once this buffering capacity is exhausted, the filter bed is removed and replaced with fresh material.

Compost beds generally have a pH between 7 and 8, a range preferred by most microorganisms. Carbon dioxide or SO_4^{2-} evolved in the metabolic activities of aerobic microorganisms tends to depress the system pH. So, if the waste gases or its intermediate by products do not provide sufficient buffering capacity, additional pH control has to be accomplished by addition of a base such as sodium or magnesium hydroxides. Although hydrogen sulfide gas can be biotrickling filtered effectively at low pH (Yang and Allen, 1994), other odorous gases like methyl sulfide may not be removed effectively (Pomery, 1982; Tanji et al., 1989).

6.1.6 Nutrients

Carbon and energy required for microorganisms may be derived from the contaminant gas, while other nutrients such as nitrogen, phosphorus, minerals, and trace elements should be supplied to microorganisms in the biotrickling filter for good performance (Auria et al., 1996). Natural packing materials (e.g., peat, compost) contain nutrients to support biomass growth but, in the case of artificial packing material, nutrients should be provided for better performance. Previous studies by Yang et al. (2002) on nitrogen requirements for biofiltration of methanol revealed that at low nitrogen levels, removal rate increased with increasing N:C ratio for both NH_3 and NO_3. At high concentrations, however, NH_3 had an inhibitory effect on the removal rate while the removal rate simply reached a plateau at high NO_3 concentrations. (Weckhuysen et al., 1993; Morgenroth et al., 1996).

6.1.7 Pressure Drop

In a biofilter, bacterial activities of biomass lead to accumulated biomass over time, which has been related to an increase in airflow resistance in the bed (Kinney et al., 1996; Mohseni et al., 1998). Biomass accumulation is greater at the inlet sections of the biofilters (Corsi and Seed, 1995; Swanson and Loehr, 1997), and leads to a change in bed characteristics e.g., reduction in interparticle void space, and the compaction of natural packing material like wood chips. These changes cause channeling and increase pressure drop.

In general, there is an approximately linear increase in pressure drop with increasing gas flow rate (Yang and Allen, 1994), which becomes exponential at higher flow rates (Morgan-Sagastume et al., 2001). In addition, at a given gas flow rate, the pressure drop increases exponentially with increasing biomass (Morgan-Sagastume et al., 2001) and with decreasing particle size, especially for particles smaller than 1 mm. The exponential increase with increasing biomass means that a lower overall pressure drop will be obtained if biomass growth is distributed along the entire filter, as opposed to being localized in specific regions (Morgan-sagatume et al., 2001). Compaction of the filter bed over extended periods of usage and due to

overwatering will also give rise to high pressure drops (Pinnette et al., 1994). Several researchers have developed predictive equations to describe pressure drops across biofilters for various particles, but there is no universal correlation that can accurately predict pressure drop for packed beds of varying particle sizes as well as the impact of biomass. Higgins et al. (1982) have developed equations for predicting pressure losses through compost piles, however, Williams (1988) found that the equation did not accurately predict head losses through a compost biofilter that utilized screened sludge compost. Morgan-Sagastume et al. (2001) developed an equation to take into account biomass growth that fit their experimental data. While these predictive tools can provide guides for media development, the variability in the physical characteristics of the media (particle size distribution, available pore space, moisture content, bulk density, etc.) biomass growth, and the characteristics of the gas (loading, particulates) should also be considered. Onsite measurements are required over a long term to thoroughly assess the pressure drop associated with a particular application.

6.1.8 Medium Depth

Biofilter medium depth range from less than 0.5 to 2.5 m. A depth of approximately 1 m appears to be most common to allow sufficient residence time while minimizing filter land area requirements. Some manufacturers recommend the use of multiple layers of biofilter media, since these will need less land area for high loading rates (Leson and Winter, 1991). Greater filter depth could be used too, but the system head loss will increase in that case, and there is also the potential for compaction of the bed at the bottom, with subsequent increase in pressure drop and channeling.

6.1.9 Waste Gas Pretreatment

The microbial communities in biotrickling filter can be poisoned by the presence of toxic contaminants, excessive concentration of the contaminant, or excursion in environmental conditions like pH, temperature, and moisture content. In

order to meet the basic requirements for optimal operation of the biotrickling filter, waste gas conditioning is often required. A sufficient supply of oxygen and humidity, and an acceptable range of temperature and pH levels in the filter bed are indispensable for the survival of the microbial community present in the bed (Werner et al., 1986; Beerli and Rotman, 1989; van Lith et al., 1990). High particulate loads in the waste gas can adversely affect the operation of a biofilter by clogging the air distribution system and the filter material itself (Willam and Miller, 1992; Bohm, 1993).

Pretreatments options can include humidification for temperature and humidity control and/or the use of devices for particulate control, such as a wet scrubber or a wet electrostatic precipitator.

6.1.10 Maintenance

The timing and frequency of routine or periodic maintenance of a biofilter depend upon a number of factors including waste gas temperature and relative humidity, filter bed moisture content, medium stability, temperature, pH, and backpressure (Leson and Winter, 1991; Yang and Allen, 1994). Fully engineered, enclosed systems with optimized packing generally reduce maintenance requirements. However, no matter how carefully a biofilter is designed, aging due to the biooxidation of organic substrates of the medium and buildup of minerals occur in most systems, which often require medium replacement.

7. Previous study on biological gas treatment

Biofilters can fail to achieve their designed removal efficiencies for various reasons, such as inadequate assessment of the waste gas stream for its contaminants, particulates and the concentration levels, variations in temperature, pH, moisture, and oxygen content within the filter bed (Standerfer and Willingham, 1996; van Lith et al., 1996). Channeling in the filter bed, bed drying, generation of acid metabolites, and system upsets due to improper gas conditioning are the probable problems

encountered during operation (Ottengraf, 1986, 1987; Leson and Winter, 1991: Leson et al., 1995; Allen and van Til, 1996).

Biological treatments using biotrickling filters have been proposed by Deshusses (1997); Kennes and Thalasso (1998); Gabriel and Deshusses (2003) as convenient alternatives for treating air streams containing low concentration of contaminants. In the packed columns, bacterial biofilm is formed on the surface of an inert packing material. The contaminated air stream is concurrently or counter-currently contacted with a liquid phase that provides nutrients and conditions to keep the viability and activity of the biofilm. The gas is absorbed in the liquid phase and biologically oxidized, thus converting H_2S compounds into oxidized sulfur compounds such as sulfur and sulfate, chemicals that will go out of the bioreactor in the liquid phase.

Comparison study on the use of compost biotrickling filter and sludge biostrickling filter as packing material in 3 stage biofilters for removing trimethylamine (TMA) from waste gases was conducted by Ding et al., (2008).

Chung et al. (1996) immobilized Thiobacillus thioparus CH_{11} with Ca-alginate to produce pellet packing material for the biofilter. At 28 second optimal retention time, the H_2S removal efficiency was more than 98%. Elemental sulfur or sulfate was produced depending on the inlet H_2S concentration. Chung et al. (1997) used *Thiobacillus novellus* in a biofilter for H_2S oxidation under mixotrophic conditions. Removal efficiency of 99.6% was achieved and the products were sulfate (83.6%) and sulfite (12.6%). Only small amount was converted to elemental sulfur. Chung et al. (2001) used biofilters packed with co-immobilized cells *Pseudomonas putida* CH_{11} and *Arthrobacter oxydans* CH_8 for removal of H_2S and NH_3, respectively, which are often present in off-gases of a livestock farm. In the 5-65 ppm range, H_2S and NH_3 removal efficiencies were greater than 96%. However, at higher concentrations, H_2S and NH_3 showed inhibitory effects on H_2S removal. They also assessed the environmental risk associated with the release of bacteria when treating large volumes

of waste gases. The exhaust gas contained small amounts of bacteria (< 19 CFU/m^3 in all cases) and was considered safe.

Elias et al. (2002) used pig manure and sawdust as packing material for biofiltration purposes. More than 90% H_2S removal efficiency was attained at a loading rate of 45 g/ m^3.h. No nutrient was added to the system and the porosity of the packing material decreased from 23.1 to 12.9%. However, this change in porosity did not affect the removal efficiency significantly and it was claimed that the biofilter could be easily cleaned by flushing water through the inlet. The main by-product of the biodegradation process was sulfur (82% of total sulfur accumulation), accompanied by sulfates and thiosulfates (<18%).

Kim et al. (2002) investigated the simultaneous removal of H_2S and NH_3 using two biofilters, one packed with wood chips and the other with granular activated carbon (GAC). A mixture of activated sludge effluent (as a source of nitrifying bacteria) and Thiobacillus thioparus (for sulfur oxidation) was sprayed on the packing materials and the drain solution of the biofilter was re-circulated to microbial population. Initially both of the filters showed high (99.9%) removal efficiency. However, due to the accumulation of elemental sulfur and ammonium sulfate on the packing materials removal efficiency decreased over time to 75 and 30% for H_2S and NH_3, respectively.

Rattanapan et al.(2009) used sulfur oxidizing bacteria which were stimulated from concentrated latex wastewater and immobilized on granular activated carbon (GAC) as a packing material for biofiltration. The comparison between the performance of sulfide oxidizing bacterium immobilized on GAC and GAC without cell immobilized systems was done. It was found that the efficiency of the H_2S removal was more than 98% even at high concentrations (200 - 4000 ppm) and the maximum elimination capacity was 125 g H_2S/m^3 of GAC/h in the biofilter with cultures.

To investigate different inorganic materials used as the packing material for the biological H_2S removal, Hirai et al (2001) compared four inorganic packing materials (porous ceramic, calcinated, cristobalite, calcinated and formed obsidians, granulated and calcinated soil). Removal efficiency and capacity were correlated with physical and chemical properties such as porosity, pore diameter, mean pore diameter. It was concluded that the selection of packing materials is an important factor affecting removal performance. Some requirements for a good packing material are as follow: (i) high water-holding capacity, (ii) high porosity and large specific surface area, (iii) less compacting nature, (iv) low-pressure drop over a wide range of water content, (v) small change in form in long periods of use, (vi) lightness, (vii) low cost, (viii) appropriate adsorbing ability for malodorous gases and (ix) large buffering capacity for acidic end products. Inorganic packing materials, such as perlite, porous ceramics, activated carbon filter and porous lava are used, because they meet requirements (iii), (iv) and (v).

Cho et al. (2000) investigated performance of low rock with immobilized *Thiobacillus* in bioflittration of H_2S. The rock showed favorable moisture retention and resisted excessive pressure drops. Removal capacities up to 428 g S/m^3.h was reported with space velocity of 300 h-1.

MATERIALS AND METHODS

Materials

Biotrickling filter system used for this research consisted of 2 fiberglass columns, packed with plastic media, connected in parallel, with supporting equipment as shown in figure 3

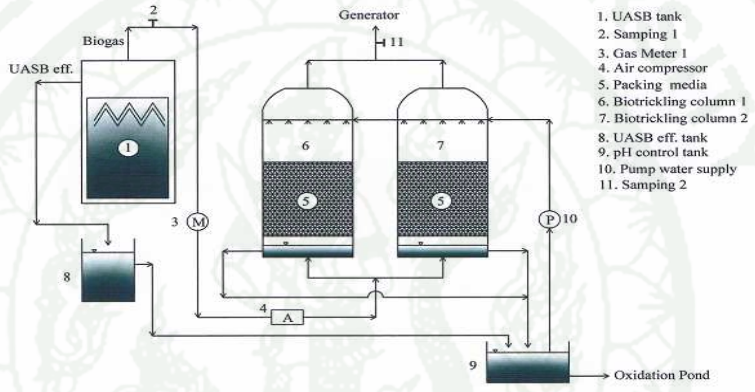

Figure 3 Schematic diagram of biotrickling filter system

Materials and equipments used in the experiment are

1. Biotrickling filter column made of fiberglass, 3.5 m. inner diameter x 8 m high. The actual system shown in appendix figure B1.
2. Filtering media made of polypropylene (PP), 130 m^2/m^3 surface area. The picture shown in appendix figure B2.
3. UASB effluent tank, Polyehtylene tank (PE) with 2,500 litre total volume.
4. Spray nozzles, Spiral type, 3/8 inch. The actual system shown in appendix figure B7.
5. Water pump, 23 m head, 390 l/min.
6. Air compressor, 25 m^3/hr

7. Gas analyzer (BM2K2-E000), for H_2S analysis in the output gas, (Biogas Check, Geotechnical Instrument, UK, Infra-red spectroscopy). The picture shown in appendix figure B3.

8. Gas analyzer (BM2K2-E000), with external gas pod, for H_2S analysis in the input gas, (Biogas Check, Geotechnical Instrument, UK, Infra-red spectroscopy). The picture shown in appendix figure B3.

9. pH controller

Methods

In the operation of biotrickling filter for H_2S removal using UASB effluent, three stages are critical. These are : 1.Initial startup, 2. Effect of reduction of moisture content and 3. Recovery from failure from various factors, such as cutoff of air, cutoff of moisture, and from power shut down due to long term shut down.

This study used full scale reactor for H_2S removal from biogas by biotrickling filter with the use of UASB effluent from a starch production plant in figure 14. The experiments were conducted at the plant in Soidao district, Chantaburi province. To determine the effects of the various factors on the operation and performance of the system, the study was divided into 3 phases, namely, the startup and performance phase, the determination of the effects of influencing factors phase and the recovery from system failure phase.

1. The startup and performance phase.

This phase consisted of the reactor preparation, bacterial inoculation, cell immobilization on the media surface and biogas feeding. To prepare the reactor, 70 m^3 of plastic media were packed into the biotrickling filter tanks. After thorough washing, the media were then filled with effluent from the UASB and left to stand overnight. It was then drained off. UASB effluent was then sprayed at the top of the

tank onto the media for six hours before biogas containing H_2S was fed into the bottom part of the reactor. To provide enough oxygen for bacterial metabolism, biogas was premixed with air before being fed into the reactor. Flow rate of biogas was 400-850 m^3/hr, flow rate of air was 25 m^3/hr. Mixed gas flow rate was in the range of 400-850 m^3/hr, containing 1000-3000 ppm. H_2S. Thus the amount of H_2S fed to the system was 0.9-2.8 kg/hr. Flow rate of UASB effluent was 96-390 L/min. Previous work by Suwanvitaya and Duangprasopsuk (2010) showed that UASB effluent contained population of *thiobacillus species*. UASB effluent acted as an inoculum, provided starter culture to biofiltration column. To investigate performance of the system, H_2S concentration in the input and output gas were determined.

In this study UASB effluent played 2 important roles, as inoculum of bacterial population in the preparation period and also as moisture provider during operation. UASB effluent was distributed by spraying nozzles. It should be low in suspended solid so that fouling of the nozzles did not occur, but should have high enough nutrients necessary for supporting bacterial growth. Suspended solid (SS) of UASB effluent used in this study was found to be 700 mg/l. It was decided that screening through No.80 screen should provide the necessary condition. After screening SS was lowered to 230 mg/L. Table 3 shows characteristics of UASB effluent before and after screening.

Table 3 Characteristics of UASB effluent (sprayed water) before and after screening

Parameters	Before screening	After screening
pH	6.8	6.9
CODt (mg/l)	1160	253
VFA (mg/l)	100	83
Alk (mg/l)	725	732

Table 3 (Continued)

Parameters	Before screening	After screening
VS_{60} (mg/l)	7	3
SS (mg/l)	770	230
Temp.	31.7	28

2. The effect of moisture content during operation.

To determine the effect of moisture content during operation three flow rates of spray water were varied, namely, 390, 195 and 97.5 l/min corresponding to 100, 50 and 25 percent of flow under normal operating condition. H_2S concentrations in the input and output gas were monitored during each flow.

3. The recovery from system failure phase

Interruption of biological process leads to system failure due to unfavorable condition for microbial activities. For the activities to resume, the system needs to be restart. In this phase, common problems occurred in actual system were simulated. The experiment focused on time needed for system recovery from failure due to loss of oxygen, loss of moisture supply and long term shut down.

3.1 Experiment on recovery from failure due to loss of oxygen conducted in the on-going system achieving satisfactory removal result. Air blower supplying to the system was shut down for 6 hours, while biogas and UASB effluent kept on flowing in the system. This made the loss of oxygen condition to the system and caused system failure. The failure was noticed by high concentration of H_2S in the output gas. After the failure, air blower was put back to work again. H_2S concentrations in the input and output gas were then monitored until H_2S removal was at the acceptable level.

3.2 Experiment on recovery from failure due to loss of moisture supply conducted in the on-going system achieving satisfactory removal result. The pump using for spraying UASB effluent to the system as moisture supply was shut down for 3 days, while biogas and air kept on flowing in the system. This made the loss of moisture condition to the system and caused system failure. The failure was noticed by high concentration of H_2S in the output gas. After the failure, the pump was put back to work again. H_2S concentrations in the input and output gas were then monitored until H_2S removal was at the acceptable level.

3.3 Experiment on recovery from long term shut down conducted in the system that had been completely shut down (without any gas nor moisture feeding in). The shut down periods under study were 1, 2 and 15 days. This condition could occur when the productions in the plant stop or when maintenance was needed. After the shut down, the system was put back to work again. H_2S concentrations in the input and output gas were then monitored until H_2S removal was at the acceptable level.

RESULTS AND DISCUSSION

The experiments on full scale reactor for H_2S removal from biogas by biotricklng filter with the use of UASB effluent was conducted at the starch production plant in Soidao district, Chantaburi province. The study was divided into 3 phases, namely, the startup and performance phase, the determination of the effects of influencing factors phase and the recovery from system failure phase. The results were as follows.

1. The startup and performance phase.

After the system set up was completed, the system, with 70 m^3 total volume of media (35m^3 in each column), was operated under a fixed flow rate of UASB effluent (spray water) of 20 m^3/hr. Mixed gas flow rate was in the range of 400-850 m^3/h, containing 1000-3000 ppm H_2S. The concentration of H_2S in biogas varied with condition of the biogas production. During the experiment, the amount of H_2S fed into biotrickling filter column fluctuated in the range of 1.00 to 3.00 kg/hr. As can be seen in Figure 4 and 5, in the first 2 days, only 52.8% of H_2S could be removed from the input gas. By the 4th day, 86.3% removal could be achieved, and H_2S concentration in the output gas met the biogas standard for use in a generator (500 ppm). This indicated that the start up time of 3-4 days gave satisfactory performance. However the removal performance was found to fluctuate with the H_2S content in the input gas. When H_2S rose up to 2.00 kg/hr, corresponding to a biogas flow rate of 400-850 m^3/hr, removal percentage dropped to 60, and H_2S outflow exceeded the standard.

When H_2S outflow exceeded the concentration limit, 28 m^3 total volume of media (14 m^3 in each column) were added. This increased the total volume of media from 70 to 98 m^3, the capacity of the reactor. The increase in media resulted in an increase in microbial population in the reactor. Within 3-4 days, the system performance recovered and even improved from before. A maximum inflow of H_2S of 2.75 kg/hr (2170 ppm at 435 m^3/hr). could be processed, with more than 95% H_2S

removed when the system became stable. Thus, it took about the same period, of 3-4 days, for the system to startup and to acclimatize to the new media content.

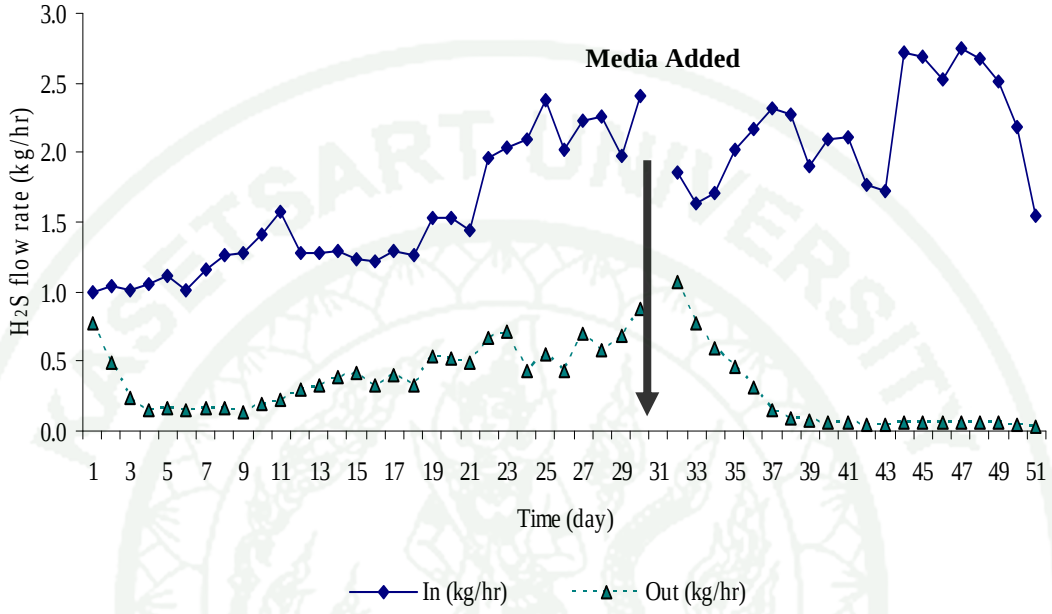

Figure 4 H_2S in the in put and output gas of Biotrickling filter column

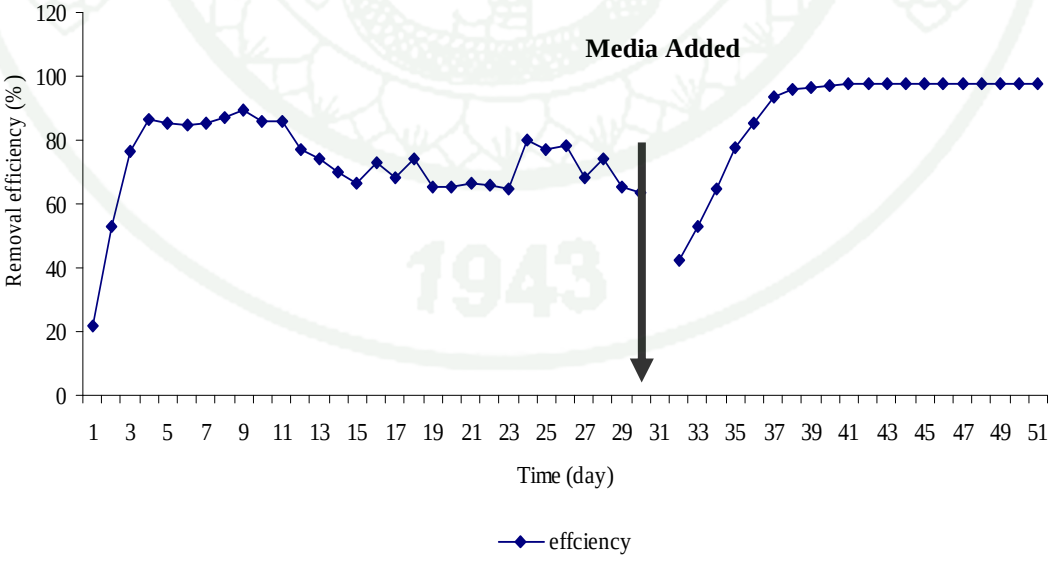

Figure 5 Removal percentage of H_2S in biotrickling filter column

2. The effect of moisture content during operation.

Reduction of moisture supply to the system can easily occur when the nozzle is clog. To simulate the problem, experiments in this phase conducted with three flow rates of spray water, namely, 390, 195 and 97.5 l/min corresponding to 100 , 50 and 25 percent of flow under normal operating condition. The results in figure 6 showed the results obtained from UASB flow rate of 390 l/min over 9 hours period. H_2S in the inlet gas was reduced from 1500 ppm. to 150-280 ppm. in the outlet gas. The removal performance was comparable when UASB flow rate was reduced to 195 and 97.5 l/min over 9 hours period (figure 7 and 8). This indicated that reduction of moisture up to 75% of normal operating condition, over 9 hour period, had no effect on removal performance. Or it could be assumed that. The system performed well at water flow rate as low as 97.5 l/min.

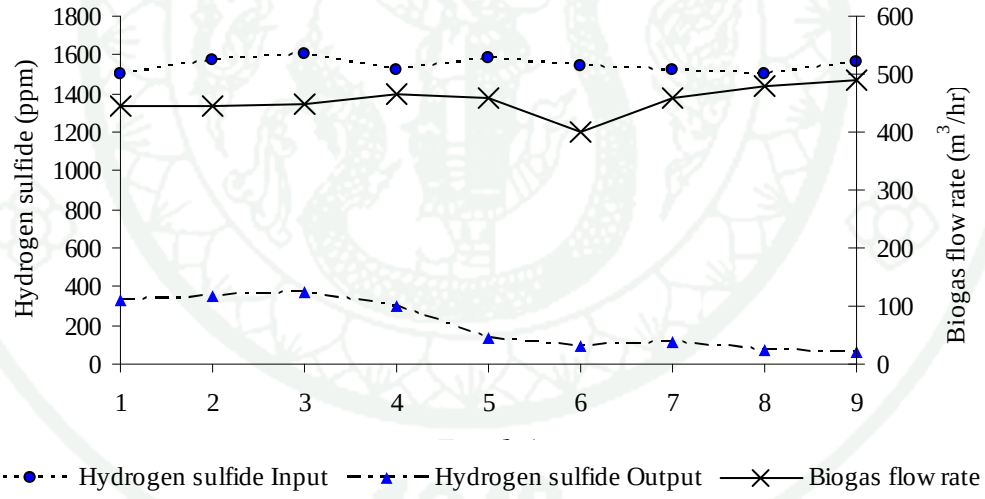

Figure 6 H_2S removal at 390 l/min UASB effluent

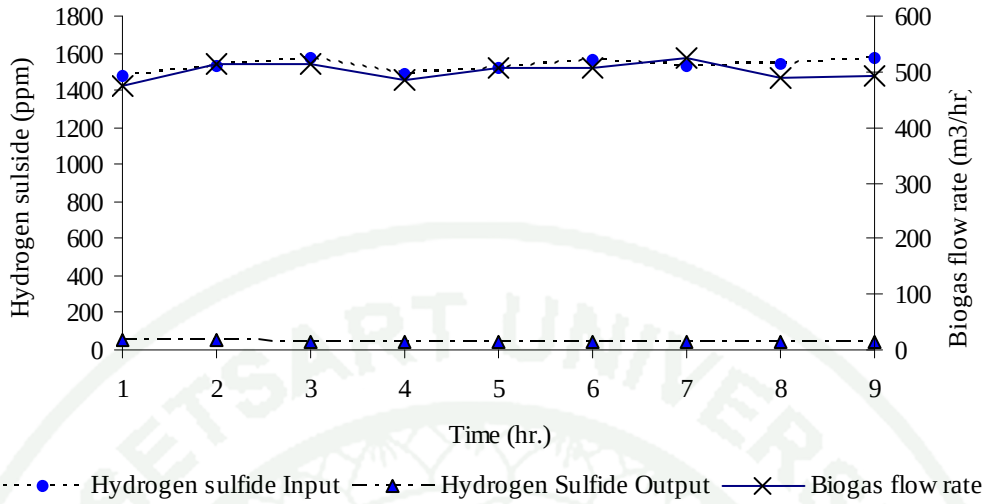

Figure 7 H_2S removal at 195 l/min UASB effluent

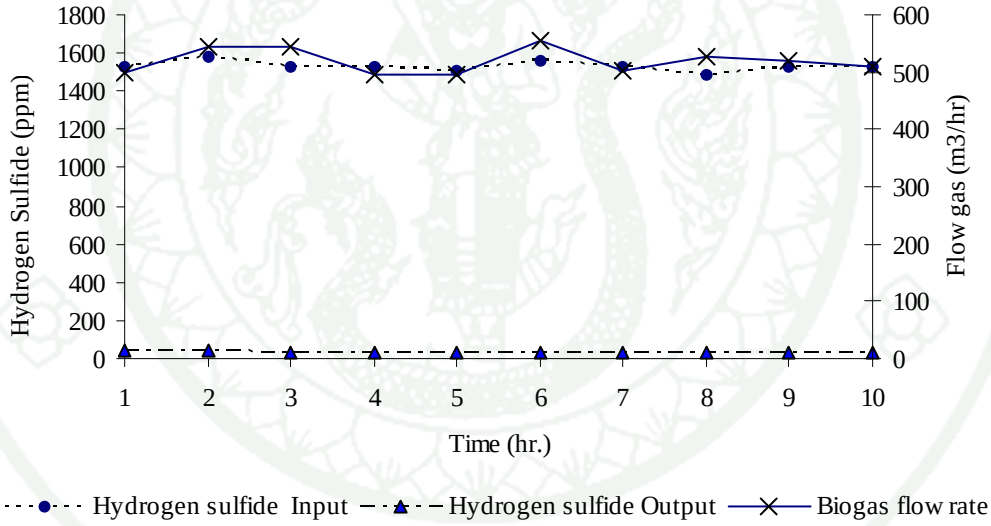

Figure 8 H_2S removal at 97.5 l/min UASB effluent

3. The recovery from system failure phase

The most possible causes of system failure include loss of oxygen, loss of moisture supply and long term shut down. The system needed to be restarted when subjected to system failure. Experiments in this phase were conducted to determine startup time for each case.

3.1 Recovery from failure due to loss of oxygen.

In this step, the system was brought to failure due to the loss of O_2, by shutting down the air blower for 6h. Figure 10 showed H_2S profile during the experiment.

Figure 9 showed the sudden rise in H_2S in the output gas when the air blower was shut down. When the air blower resumed to work, H_2S concentration in the outlet gas began to reduce. The system took 4-5 days to be fully recovered.

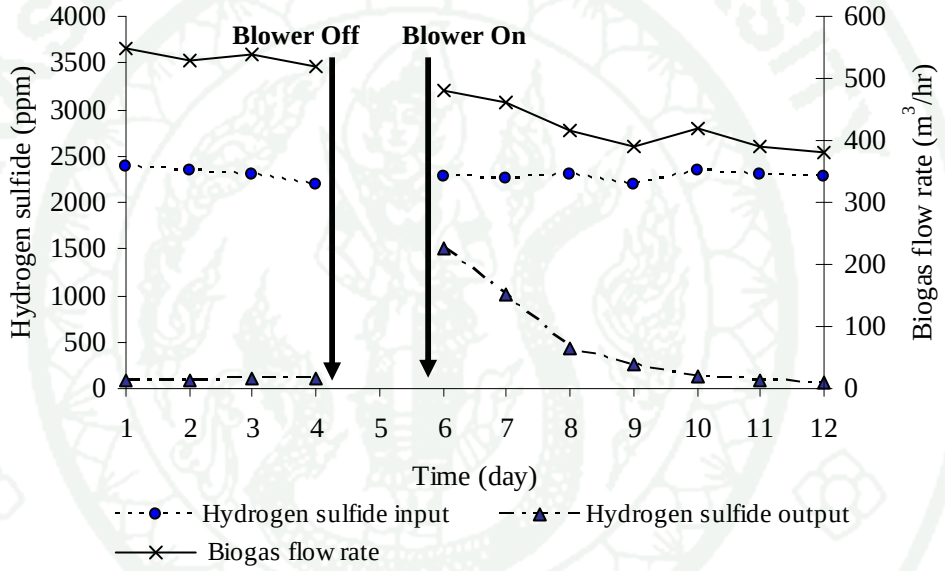

Figure 9 System recovery from loss of oxygen.

3.2 Recovery from failure due to loss of moisture supply.

The shut down of the pump for 3 days made the system failed to remove H_2S due to loss of moisture. Figure 10 showed system performance when the pump was shut off and put back to work again. A significant amount of H_2S was removed (2960-1900) immediately after the pump resumed. The removal pattern was again similar to that of the start up. By the 4^{th} day the system was fully recovered leaving 380 ppm H_2S in the output gas. The recovery period equal to start up period.

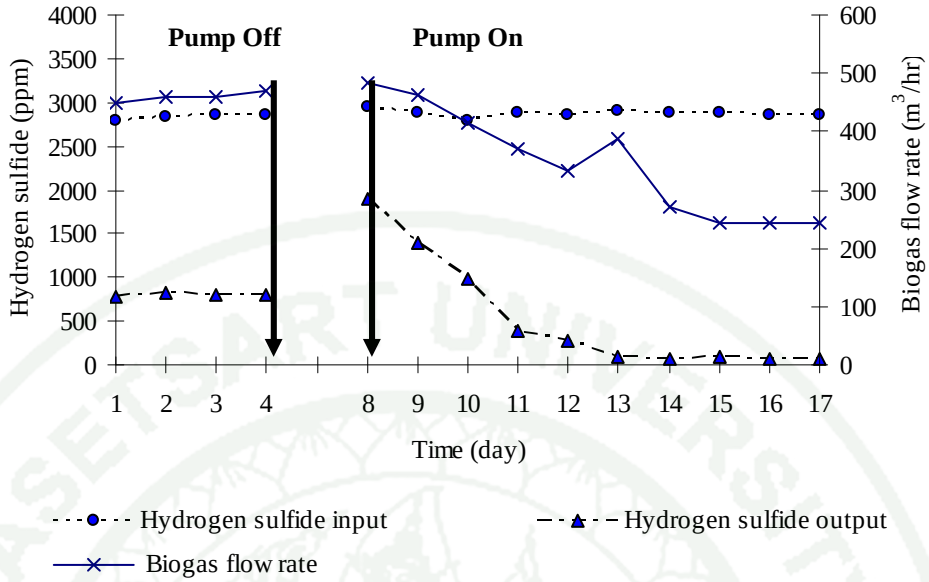

Figure 10 System recovery from loss of moisture

3.3 Recovery from system shut down.

In this step, the system was completely shut down (with neither gas nor moisture supply) for the periods of 1, 2 and 15 days. The results (Figures 11 and 12) obtained from 1 and 2 days shut down period were the same, with patterns similar to that of system startup. Time needed for the system to full recovery was about 4-5 days.

The results of the 15 days shut down were found to be slightly different. Figure 13 showed a 2 days lag in H_2S removal. No lag occurred with the recovery from 1 and 2 days shut down. The lag in recovery observed from the 15 days shut down was attributed to acclimatization of the microbial population.

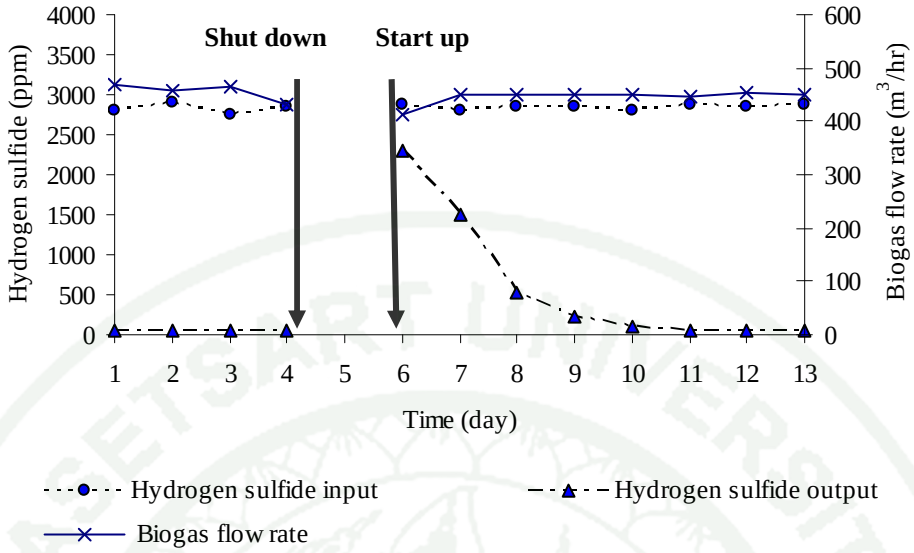

Figure 11 Recovery period due to system failure from 1 day shut down

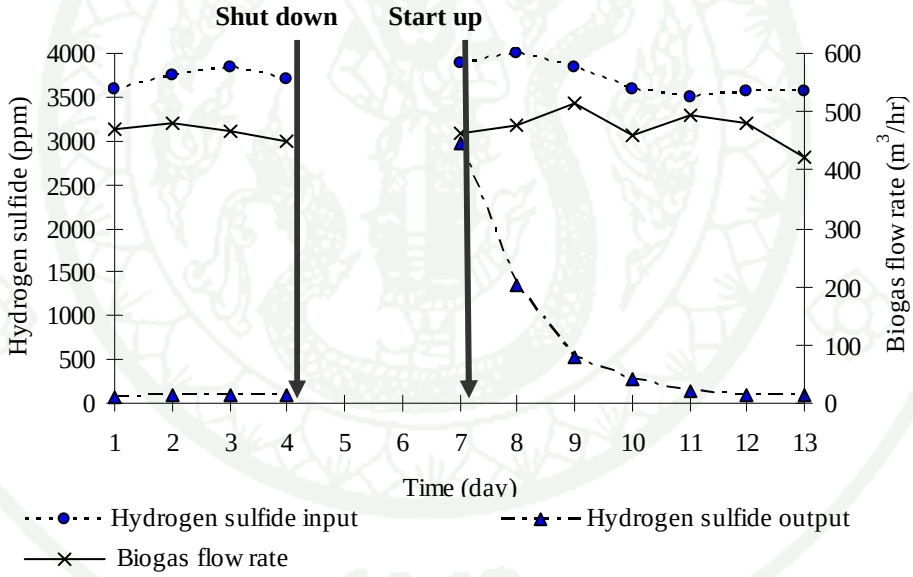

Figure 12 Recovery period due to system failure from 2 days shut down

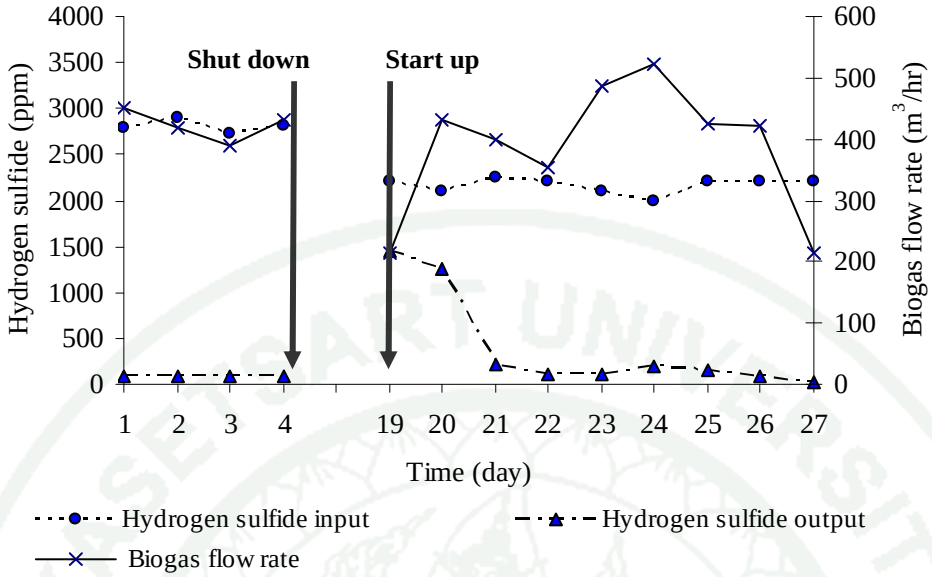

Figure 13 Recovery period due to system failure from 15 days shut down

CONCLUSION

In this study full scale biotrickling filter was constructed from fiberglass reianforced plastic (FRP) shells, with 3.5 m. inner diameter and 8 m. height. with 70 m^3 total volume of media (35m^3 in each column), was operated under a fixed flow rate of UASB effluent (spray water) of 20 m^3/hr. Mixed gas flow rate was in the range of 400-850 m^3/h, containing 1000-3000 ppm. H_2S. The concentration of H_2S in biogas varied with condition of the biogas production. During the experiment, the amount of H_2S fed into biotrickling filter column fluctuated in the range of 1.00 to 3.00 kg/hr.

1. The system took 3-4 days from start up to reach steady state, achieving 86% H_2S removal. It took about the same period to adjust when media content was increased.

2. Threshold loading of H_2S to the system was at 2.00 kg/hr, for media volume of 70 m^3, beyond this point the removal percentage dropped sharply.

3. Reduction of moisture supply to 50 and 25 percent of normally flow rate over a 9 period showed no observable effect on H_2S removal. The system performed well at water flow rate as low as 97.5 l/min.

4. Recovery from failure due to the loss of O_2 was similar to start up, taking 4 days to achieve steady state. The same recovery pattern and time was obtained with the loss of moisture.

5. Recovery from all 3 periods of complete shut down (1, 2 and 15 d) was 4 days with the same pattern to the start up but a 2 day lag in removal activity was encountered in the long shut down period of 15 d.

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APPENDICES

Appendix A

Experiment Data

Appendix Table A1 Raw data : Start up and performance, H_2S in the input and Output gas.

Date	day	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
11/11/2010	1	410	2410	1890
12/11/2010	2	430	2150	1137
13/11/2010	3	420	2100	560
14/11/2010	4	435	2170	330
15/11/2010	5	463	2200	350
16/11/2010	6	416	2479	367
17/11/2010	7	480	2690	350
18/11/2010	8	525	2980	310
19/11/2010	9	529	3070	250
20/11/2010	10	584	2820	335
21/11/2010	11	652	2670	340
22/11/2010	12	528	2730	557
23/11/2010	13	528	2750	629
24/11/2010	14	539	3100	720
25/11/2010	15	513	3390	810
26/11/2010	16	504	2930	652
27/11/2010	17	535	2940	761
28/11/2010	18	521	2430	625
29/11/2010	19	634	2830	842
30/11/2010	20	635	2540	830
1/12/2010	21	599	2775	811
2/12/2010	22	812	2795	823
3/12/2010	23	842	2965	849
4/12/2010	24	870	2460	487
5/12/2010	25	986	2900	558
6/12/2010	26	841	3115	520
7/12/2010	27	922	2365	761
8/12/2010	28	938	2935	625
9/12/2010	29	818	2740	842

Appendix Table A1 (Continued)

Date	Day of operation	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
10/12/2010	30	999	3025	876
11/12/2010	31	883	3425	1595
12/12/2010	32	769	3250	1395
13/12/2010	33	678	3075	1140
14/12/2010	34	706	3360	845
15/12/2010	35	841	3355	545
16/12/2010	36	899	3450	350
17/12/2010	37	960	3150	150
18/12/2010	38	945	3290	98
19/12/2010	39	791	3180	85
20/12/2010	40	871	3200	76
21/12/2010	41	875	3425	61
22/12/2010	42	734	3250	54
23/12/2010	43	712	3200	57
24/12/2010	44	1130	3430	53
25/12/2010	45	1115	3295	58
26/12/2010	46	1045	3220	55
27/12/2010	47	1142	2655	56
28/12/2010	48	1110	2845	55
29/12/2010	49	1042	2505	56
30/12/2010	50	905	2350	55
31/12/2010	51	639	2695	53

Appendix Table A2 Raw data : Start up and performance, H_2S loading efficiency.

Date	day	flow Gas (m^3/hr)	H_2S In (ppm)	H_2S Out (ppm)	H_2S In (kg/hr)	H_2S Out (kg/hr)	Efficiency %
11/11/2010	1	410	2410	1890	0.988	0.775	21.6%
12/11/2010	2	430	2150	1137	1.036	0.489	52.8%
13/11/2010	3	420	2100	560	1.012	0.235	76.8%
14/11/2010	4	435	2170	330	1.048	0.144	86.3%
15/11/2010	5	463	2200	350	1.116	0.162	85.5%
16/11/2010	6	416	2479	367	1.003	0.153	84.8%
17/11/2010	7	480	2690	350	1.157	0.168	85.5%
18/11/2010	8	525	2980	310	1.265	0.163	87.1%
19/11/2010	9	529	3070	250	1.275	0.132	89.6%
20/11/2010	10	584	2820	335	1.407	0.196	86.1%
21/11/2010	11	652	2670	340	1.571	0.222	85.9%
22/11/2010	12	528	2730	557	1.272	0.294	76.9%
23/11/2010	13	528	2750	629	1.272	0.332	73.9%
24/11/2010	14	539	3100	720	1.299	0.388	70.1%
25/11/2010	15	513	3390	810	1.236	0.416	66.4%
26/11/2010	16	504	2930	652	1.215	0.329	72.9%
27/11/2010	17	535	2940	761	1.289	0.407	68.4%
28/11/2010	18	521	2430	625	1.256	0.326	74.1%
29/11/2010	19	634	2830	842	1.528	0.534	65.1%
30/11/2010	20	635	2540	830	1.530	0.527	65.6%
1/12/2010	21	599	2775	811	1.444	0.486	66.3%
2/12/2010	22	812	2795	823	1.957	0.668	65.9%
3/12/2010	23	842	2965	849	2.029	0.715	64.8%
4/12/2010	24	870	2460	487	2.097	0.424	79.8%
5/12/2010	25	986	2900	558	2.376	0.551	76.8%
6/12/2010	26	841	3115	520	2.027	0.437	78.4%
7/12/2010	27	922	2365	761	2.222	0.702	68.4%
8/12/2010	28	938	2935	625	2.261	0.586	74.1%
9/12/2010	29	818	2740	842	1.971	0.689	65.1%
10/12/2010	30	999	3025	876	2.408	0.875	63.7%
11/12/2010	31			Added	Media		

Appendix Table A2 (Continued)

Date	day	flow Gas (m^3/hr)	H_2S In (ppm)	H_2S Out (ppm)	H_2S In (kg/hr)	H_2S Out (kg/hr)	Efficiency %
12/12/2010	32	769	3250	1395	1.853	1.073	42.1%
13/12/2010	33	678	3075	1140	1.634	0.773	52.7%
14/12/2010	34	706	3360	845	1.701	0.597	64.9%
15/12/2010	35	841	3355	545	2.027	0.458	77.4%
16/12/2010	36	899	3450	350	2.167	0.315	85.5%
17/12/2010	37	960	3150	150	2.314	0.144	93.8%
18/12/2010	38	945	3290	98	2.277	0.093	95.9%
19/12/2010	39	791	3180	85	1.906	0.067	96.5%
20/12/2010	40	871	3200	76	2.099	0.066	96.8%
21/12/2010	41	875	3425	61	2.109	0.053	97.5%
22/12/2010	42	734	3250	54	1.769	0.040	97.8%
23/12/2010	43	712	3200	57	1.716	0.041	97.6%
24/12/2010	44	1130	3430	53	2.723	0.060	97.8%
25/12/2010	45	1115	3295	58	2.687	0.065	97.6%
26/12/2010	46	1045	3220	55	2.518	0.057	97.7%
27/12/2010	47	1142	2655	56	2.752	0.064	97.7%
28/12/2010	48	1110	2845	55	2.675	0.061	97.7%
29/12/2010	49	1042	2505	56	2.511	0.058	97.7%
30/12/2010	50	905	2350	55	2.181	0.050	97.7%
31/12/2010	51	639	2695	53	1.540	0.034	97.8%

Appendix Table A3 Raw data: Effect of O_2 supply on H_2S output, at 25 m^3/hr continually.

Operation Time (min)	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
1	410	2400	1985
2	410	2400	1980
3	410	2400	1975
4	410	2400	1900
5	410	2400	1825
6	410	2400	1798
7	410	2400	1645
8	410	2400	1447
9	410	2400	1238
10	410	2400	1200
11	410	2400	1180
12	410	2400	1100
13	410	2400	1090
14	410	2400	1076
15	410	2400	1060
16	410	2400	1000
17	410	2400	980
18	410	2400	920
19	410	2400	850
20	410	2400	790
21	410	2400	750
22	410	2400	710
23	410	2400	690
24	410	2400	617
25	410	2400	550
26	410	2400	525

Appendix Table A3 (Continued)

Operation Time (min)	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
27	410	2400	500
28	410	2400	450
29	410	2400	435
30	410	2400	440
31	410	2400	435
32	410	2400	430
33	410	2400	420
34	410	2400	410
35	410	2400	400
36	410	2400	390
37	410	2400	380
38	410	2400	370
39	410	2400	360
40	410	2400	350
41	410	2400	340
42	410	2400	330
43	410	2400	320
44	410	2400	310
45	410	2400	300
46	410	2400	300
47	410	2400	280
48	410	2400	270
49	410	2400	265
50	410	2400	255
51	410	2400	240
52	410	2400	230
53	410	2400	220
54	410	2400	215

Appendix Table A3 (Continued)

Operation Time (min)	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
55	410	2400	215
56	410	2400	200
57	410	2400	210
58	410	2400	210
59	410	2400	190
60	410	2400	195
61	410	2400	186
62	410	2400	180
63	410	2400	175
64	410	2400	174
65	410	2400	160
66	410	2400	154
67	410	2400	150
68	410	2400	150
69	410	2400	148
70	410	2400	140
71	410	2400	130
72	410	2400	110
73	410	2400	112
74	410	2400	105
75	410	2400	100
76	410	2400	98
77	410	2400	97
78	410	2400	99
79	410	2400	100
80	410	2400	98

Appendix Table A4 Raw data: The effect of moisture content during operation, Rate of feed UASB eff. = 390 l/min.(100%)

Time of operation (hr.)	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
0:30	446	1530	330
1:00	445	1530	350
2:00	449	1530	370
3:00	464	1530	297
4:00	458	1530	130
5:00	400	1530	92
6:00	460	1530	115
7:00	480	1530	72.3
8:00	488	1530	61.3

Appendix Table A5 Raw data: The effect of moisture content during operation**,** Rate of feed UASB eff. = 195 l/min. (50%)

Time of operation (hr.)	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
9:00	476	1530	55
9:30	512	1530	52
10:00	512	1530	48
10:30	486	1530	45
11:00	506	1530	43
11:30	507	1530	45
12:00	526	1530	43
12:30	488	1530	43
13:00	491	1530	40

Appendix Table A6 Raw data: The effect of moisture content during operation, Rate of feed UASB eff. = 97.5 l/min. continuous. (25%)

Time of operation (hr.)	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
13:30	500	1530	41
13:45	545	1530	37
14:00	544	1530	36
14:30	497	1530	35
15:00	494	1530	32
15:30	556	1530	33
16:00	502	1530	32
16:30	526	1530	32
17:00	520	1530	32
17:30	510	1530	32

Appendix Table A7 Raw data: Recovery from failure due to loss of oxygen.

Day of operation	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
1	550	2380	90
2	530	2350	85
3	540	2300	110
4	520	2200	100
Blower off			
6	482	2290	1900
7	462	2250	1010
8	415	2300	430
9	390	2200	260
10	420	2350	120
11	390	2300	90
12	380	2290	70

Appendix Table A8 Raw data: Recovery from failure due to loss of moisture supply.

Day of operation	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
1	450	2800	780
2	460	2840	815
3	460	2850	800
4	470	2850	790
Pump off 3 days			
8	482	2960	1900
9	462	2870	1400
10	415	2800	980
11	371	2870	380
12	332	2850	270
13	388	2910	83
14	271	2890	75
15	243	2870	81
16	243	2850	64
17	243	2850	60

Appendix Table A9 Raw data: Recovery from system shut down (1 day)

Day of operation	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
1	470	2800	56
2	457	2900	54
3	465	2750	60
4	430	2850	55
Shut down system			
6	414	2870	2300
7	451	2800	1500
8	451	2850	520
9	449	2840	230
10	450	2810	89
11	445	2870	56
12	453	2860	62
13	450	2880	59

Appendix Table A10 Raw data: Recovery from system shut down (2 days)

Day of operation	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
1	470	3600	80
2	480	3740	87
3	465	3850	95
4	450	3700	90
Shut down system			
7	464	3880	2970
8	476	3990	1350
9	516	3840	520
10	459	3600	280
11	494	3490	140
12	480	3560	90
13	421	3560	89

Appendix Table A11 Raw data: Recovery from system shut down (15 days)

Day of operation	flow Gas (m^3/hr)	Gas In H_2S(ppm)	Gas Out H_2S(ppm)
1	450	2780	80
2	420	2900	87
3	390	2730	95
4	430	2820	90
Shut down system			
19	213	2200	1446
20	432	2100	1253
21	399	2250	210
22	355	2200	113
23	486	2100	105
24	512	2000	196
25	424	2200	144
26	241	2200	90
27	213	2200	18

Appendix B

The picture of system used in the study

Appendix Figure B1 Full-scale biotrickling filter at UASB wastewater treatment plant for starch production (Soidao District, Chanthaburi Province)

Appendix Figure B2 Plastic media for packing in the full-scale biotrickling filter tank. Material is Polypropylene Plastic (PP), Surface Area is 130 m2 /m^3. Specific Gravity 0.95, Standard Size diameter in is 97 mm., diameter out is 105 mm., Height is 37 mm., Number is 2000 n/m^3, Weight is 34 g/n, Bulk Density is 68 kg./m^3

Appendix Figure B3 Gas analyzer (Biogas check). CH_4, CO_2, O_2, H_2S are measured by the gas detector (Biogas check, Geotechnical Instrument, UK)

Appendix Figure B4 Storage pond for raw waste water from factory

Appendix Figure B5 UASB Effluent

Appendix Figure B6 Oxidation Pond used as storage UASB eff. and Biotrickling filter effluent.

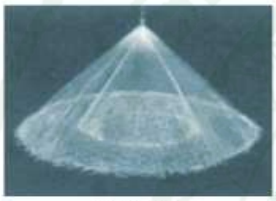
The SPJT WhirlJet nozzle

DESIGN FEATURES

The SPJT WhirlJet nozziesproduce a solid cone spray pattern with spray angles ranging from 60° to 170° . The liquid flow rate ranged from 5.5 liters per minute to 4140 liters per minute at 3 bar. These compact nozzles permit maximum liquid throughputfor a given pipe size, and the free passage design minimizes clogging.

These nozzles can be installed on and replaced from most pipe systems. They are available in brass , 316 stainless steel and TEFLON for 1/4 to 2 inch inlet connection sizes. Other materials are available in case of application in some special fields.

SPRAY PATTERN



Solid cone

Hollow cone

PERFORMANCE DATA

Inlet Conn. NPY or BSPT(M)	Spray Angle(0.7bar)					Capacity Size	Orifice diameter mm	Free Passage Diameter mm	Capacity(L/M)				
	60°	90°	120°	150°	170°				0.78ar	1.58ar	38ar	78ar	258ar**
1/4	●	●	●			07	2.4	2.4	2.6	3.9	5.5	8.4	16
	●	●	●	●	●	13	3.2	3.2	4.9	7.3	10.3	15.7	30
	●	●	●	●	●	20	4.0	3.2	7.6	11.2	15.8	24	46
3/8	●					07	2.4	2.4	2.6	3.9	5.5	8.4	16
	●					13	3.2	3.2	4.9	7.3	10.3	15.7	30
	●					20	4.0	3.2	7.6	11.2	15.8	24	46
	●	●	●	●	●	30	4.8	3.2	11.4	16.7	24	36	68
	●	●	●	●	●	40	5.6	3.2	15.1	22	32	48	91
	●	●	●	●	●	53	6.4	3.2	20	30	42	64	121
	●	●	●	●	●	82	7.9	3.2	31	46	65	99	187
1/2	●	●	●	●	●	120	9.5	4.8	45	67	95	145	270
	●	●	●	●	●	164	11.1	4.8	62	92	129	198	370
3/4	●	●	●	●	●	210	12.7	4.8	80	117	166	255	480
1	●	●	●	●	●	340	15.9	6.4	130	190	270	410	775
	●	●	●	●	●	470	19.1	6.4	179	260	370	565	1070
1-1/2	●	●	●	●	●	640	22.2	7.9	245	355	505	770	1460
	●	●	●	●	●	820	25.4	7.9	310	455	645	990	1870
	●	●	●	●	●	960	28.6	7.9	365	535	755	1160	2190
2	●	●	●	●	●	1400	34.9	11.1	535	780	1105	1690	3190
	●	●	●	●	●	1780	38.1	11.1	680	995	1405	2150	4060
3	●	●	●			2560	44.5	14.3	980	1430	2020	3090	5830
	●	●	●			3360	50.8	14.3	1280	1880	2650	4050	7660
4	●	●	●			5250	63.5	15.9	2000	2930	4140	6330	11960

** Brass and 316 stainless steel are needed in case of larger pressures

COMMON APPLICATIONS

- Flue Gas Washing
- Gas Cooling
- Washing and Rinsing
- Fire Prevention&Fire Suppression

Appendix Figure B7 Spray nozzle

Appendix C

2011 International Conference on Environmental Quality Concern, Control and Conservation

2011 International Conference on Environmental Quality Concern, Control and Conservation

Organized by

Department of Marine Environmental Engineering, National Kaohsiung Marine University, Taiwan.

Department of Environmental Resources and Management, Chia Nan University of Pharmacy and Science, Taiwan.

Co-organized by

King Mongkut's University of Technology Thonburi, Thailand.
National Center of Excellent for Environmental and Hazardous Waste Management, Thailand.
Hanoi University of Technology, Vietnam.

May 20-21, 2011
Kaohsiung, Taiwan

Session C-3: 14: 50 – 15:50; Huan-Yu Building, Room 2204

Chair: Professor I-Ming Chen
Student Co-Chair: Chun-Yu Lin

14: 50 – 15: 10	**Distribution of Butyltins in Sediments of the Ocean Disposal Site of Kaohsiung Harbor** Yun Lung Lin, Chiu Wen Chen, Yu Sung Hsiao, Chih Feng Chen, Cheng Di Dong	**I-27**
15: 10 – 15: 30	**Treatability Studies on Arsenic Removal from Synthetic Contaminated Water Using Electrodialysis** Rose Marie O. Mendoza, Chi-chuan Kan, Ma. Lourdes P. Dalida, Meng-Wei Wan	**I-29**
15: 30 – 15: 50	**H_2S Removal in Full Scale Biotrickling Filter with Uasb Effluent** Nittiya Ngaonee and Patcharaporn Suwanvitaya	**I-32**
15: 50 – 16: 10		
16: 10 – 16: 30	**Closing Ceremony/ to be held at Administration Building, 7th Floor**	
16: 30 – 17: 30	**Technical Tour**	

Certificate of Participation

This is to certify that

Kasetsart University

Nittiya Ngaonee

has participated in the

2011 International Conference on Environmental Quality Concern, Control and Conservation

Chitsan Lin

Ph.D., P.E.
Chairman of the EQC^3
May 20, 2011.

International Conference on Environmental Quality Concern, Control and Conservation, May 20, 2011, National Kaohsiung Marine University, Kaohsiung, Taiwan.

H_2S REMOVAL IN FULL SCALE BIOTRICKLING FILTER WITH UASB EFFLUENT

Nittiya Ngaonee and Patcharaporn Suwanvitaya

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ABSTRACT

Biogas from UASB system contains a small percentage of H_2S which must be removed before the biogas can be utilized in electricity generation. H_2S removal by biological process is successful in laboratories and in full scale reactors. The experiment on H_2S removal in a full scale biotrickling was conducted. The biogas contaminated with H_2S used in the study was obtained from UASB system treating wastewater from a starch production plant. The reactor consisted of 2 columns connected in parallel. Each column was of 3.5 m inner diameter x 8 m high, packed with 35 m^3 plastic media. Biogas with 1,000 to 3,000 ppm H_2S was mixed with air and was upwardly fed into the column at 400-850 m^3/hr. UASB effluent was sprayed on top and trickled down the column at 23 m^3/hr. Start up time of the system was 3-4 days, achieving 89.6 percent H_2S removal. Loss of O_2 resulted in the decrease in removal percentage, with 2 minutes lag time. The system could resist a short period (less than 10 hours) moisture loss. Performance failure of the system due to complete shut down 1, 2 and 15 days could be recovered within 4-5 days.

KEYWORDS : Biotrickling filter, Hydrogen sulfide, UASB effluent, Biogas

CURRICULUM VITAE

NAME : Miss Nittiya Ngaonee

BIRTH DATE : February 23, 1977

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EDUCATION :	**YEAR**	**INSTITUTE**	**EGREE/DIPLOMA**
	1999	Mahanakorn Univ.	B.Eng. (Civil)
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