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Ultrasonic membrane anaerobic system (UMAS) applications intreating slaughterhouse wastewater

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ABSTRACT

In the wake of energy crisis and the drive to reduce CO_2 emissions, the alternative energy sources are much demanded in order to reduce energy consumption, to meet legal requirements on emissions, and for cost reduction and increased quality. The direct discharge of slaughterhouse wastewater causes serious environmental pollution due to its high chemical oxygen demand (COD), Total suspended solids (TSS) and biochemical oxygen demand (BOD). The traditional methods for treating slaughterhouse wastewater have two undesired aspects which areeconomic and environmental. Therefore, as alternative, ultrasonic membrane anaerobic system (UMAS) was used, as cost effective method for treating slaughterhouse wastewater.Experimentsresults have shown that the mixed liquor volatile suspended solids (MLSS) concentration ranges from7,800 to 13,620 mg/l while mixed liquor volatile suspended solids (MLVSS) rangeswas 5,359 to 11,424 mg/l. Three kinetic models were used to fit the kinetic models of slaughterhouse treatment at organic loading rates ranging from 3 to 11 kg COD/m^3/d. UMAS performance has shown the COD removal efficiencywas from 94.8 to 96.5% with hydraulic retention time, HRT from 308.6 to 8.7 days. The coefficient of growth yield, Y was found to be 0.52gVSS/g COD the specific microorganism decay rate was 0.21 d^{-1} and the methane gas yield production rate was between 0.24 l/g COD/d and 0.56 l/g COD/d.

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INTRODUCTION

The slaughterhouse wastewaters arises from different steps of the slaughtering process such as washing of animals, bleeding out, skinning, cleaning of animal bodies, cleaning of rooms, etc. the main pollutant in slaughterhouse effluents is organic matter. The contributions of organic load to these effluents are blood, particles of skin and meat, excrements and other pollutants. Slaughterhouse wastewater is very harmful to the environment; therefore, it must be treated before it discharged. In 2011, more than 36 million tons of food waste was generated in the U.S. (U.S. EPA, 2013). Food waste has higher biochemical methane potential. An aerobic digestion of food waste not only produces methane for energy recovery, but also treats waste for environmental and social benefits (Fuchs and Drosg, 2013; Izumi *et al*., 2010; Zhang *et al*., 2013). In the cited literature, several technologies to treat slaughterhouse wastewater have been proposed; including physico-chemical methods (e.g. dilution, evaporation, sedimentation) and biological methods (e.g. aerobic pretreatment, anaerobic digestion (Paraskeva*et al*., 2006). Effluent discharge from slaughterhouses has caused the deoxygenation of rivers (Zagklis*et al*, 2013) and the contamination of groundwater (Sangodoyin*et al*., 1992). The pollution potential of meat-processing and slaughterhouse plants has been estimated at over 1 million population equivalent in the Netherlands (Sayed, 2005), and 3 million in France. Blood, one of the major dissolved pollutants in slaughterhouse wastewater, has a chemical oxygen demand (COD) of 375000 mg/l(Zhang *et al*., 2013). Slaughterhouse wastewater has high concentrations of suspended solids(SS), including pieces of fat, grease, hair, feathers, flesh, manure, grit, and undigested feed. These insoluble and slowly biodegradable SS represented 50% of the pollution charge in screened (1 mm) slaughterhouse wastewater, while another 25% originated from colloidal solids (Izumi *et al*., 2010). Typical characteristics of wastewater from slaughterhouse are given in Table 1.

Table 1: Characteristics of the wastewater from the slaughterhouses (Quinn *et al*., 1989)

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Parameter	Concentration (g/l)
pH	6.8-7.8
COD	5.2-11.4
TSS	0.57-1.69
Phosphorus	0.007-0.0283
Ammoniacal nitrogen	0.019-0.074
Protein	3.25-7.86

Slaughterhouse wastewater quality depends on a number of factors, namely:

1. Blood capture: the efficiency in blood retention during animal bleeding is considered to be the most important measure for reducing biological oxygen demand (BOD) (Palmowski*et al*., 2000).
2. Water usage: water economy usually translates into increased pollutant concentration, although total BOD mass will remain constant.
3. Type of animal slaughtered: BOD is higher in wastewater from beef than hog slaughterhouses (Palmowski*et al*., 2000)
4. Amount of rendering or meat processing activities: plants that only slaughter animals produce a stronger wastewater than those also involve in rendering or meat processing activities.

Most slaughterhouse wastewater quality data have been generated in Europe(Sayed *et al*., 2005; Palmowski*et al*., 2000 and Sayed *et al*., 1988).

Anaerobic ponds have been used for wastewater treatment in a purposeful manner for more than half a century. However, this suffers from the disadvantage of odour generation from the ponds thus making the development of alternate designs very essential. Anaerobic contact, up-flow anaerobic sludge blanket, and anaerobic filter reactors have been tried for slaughterhouse wastes. All these have a higher organic loading rate, OLR ranging from 5 to 40 kg COD/m^3/day (Ruiz *et al*., 1997). The high rate anaerobic treatment systems such as UASB and fixed bed reactors are less popular for slaughterhouse wastes due to the presence of high fat oil and suspended matters in the influent. This affects the performance and efficiency of the treatment systems. Also, because of relatively low BOD, high rate systems which function better for higher BOD concentrations are not appreciate. Table 2 summarizes the performance data of digesters used for the treatment of slaughterhouse wastewater. In recent years, considerable attention has been paid towards the development of reactors for anaerobic treatment of wastes leading to the conversion of organic molecules into biogas. These reactors, known as second generation reactors or high rate digesters, can handle wastes at a high organic loading rate of 24 kg COD/m^3/day and high up-flow velocity of 2-3 m/h at a low hydraulic retention time (Ruiz *et al*., 1997). However, the treatment efficiencies of these reactors are sensitive to parameters like wastewater composition, especially the concentration of various ions (Ruiz *et al*., 1997; Johns, 1995) and presence of toxic compounds such as phenol (Lettinga, 1995). The temperature and pH are also known to affect the performance of the reactor by affecting the degree of acidification of the effluent and the product formation (Zhang *et al*., 1996). Table 2 shows some treatment systems for slaughterhouse wastes, while Table 3 shows mathematical expressions for specifics substrate utilization rate for three kinetic models.

Table 2: Treatment systems for slaughterhouse wastes (Sangodoyin*et al*., 1992)

Reactor	Capacity (m^3)	OLR (kg COD/m^3/day)	Reduction (%)
UASB (granular)	33	11	85
UASB (flocculated)	10	5	80-89
Anaerobic filter	21	2.3	85
Anaerobic contact	11, 120	3	92.6

Table 3: Mathematical expressions of specifics substrate utilization rates for known kinetic models

Kinetic Model	Equation 1	Equation 2
Monod	$U=\frac{k\,S}{k_s+S}$	$\frac{1}{U}=\frac{K_s}{K}(\frac{1}{S})+\frac{1}{k}$ (1949)
Contois	$U=\frac{U_{\max}\times S}{Y(B\times X+S)}$	$\frac{1}{U}=\frac{a\times X}{\mu_{\max}\times S}+\frac{Y(1+a)}{\mu_{\max}}$ (1959)
Chen & Hashimoto	$U=\frac{\mu_{\max}\times S}{Y\,K\,S_o+(1-K)\,S\,Y}$	$\frac{1}{U}=\frac{Y\,K\,S_o}{\mu_{\max}\,S}+\frac{Y(1-K)}{\mu_{\max}}$ (1980)

Slaughterhouse wastewater has been classified as industrial waste in the agricultural and food industries category. Wastewaters from slaughterhouses and meatal processing industries have been classified by Environmental Protection Agency (EPA) as one of the most harmful to the environment (Walter *et al*., 1974). For the treatment of this type of wastes, Conventionalbiological processes do not offer the solution to satisfy environmental requirements.

(Mudrak*et al*., 1986). Another common problem encountered in the industrial anaerobic plants is biomass washout. This can be addressed, for instance, by the use of membranes coupled with the anaerobic digester for biomass retention (Fang *et al*., 1997). This paper introduces a new technique, which Ultrasonic membrane anaerobic system (UMAS) for slaughterhouse wastewater treatment. This system, UMAS avoid and solve the membrane fouling problems.

1.1 Literature on Slaughterhouse Wastewater Treatment:

1.1.1Pre-treatment Sewer discharge system:

For the treatment of slaughterhouse wastes, Conventionalbiological processes do not offer the solution to satisfy environmental requirements. As an alternative to more efficient treatment process for treating highly loaded effluents, the anaerobic process is particularly designed to effluents discharged at high concentrations of COD and other biodegradable components. Meat processing effluents exhibit high organic and inorganic load. High suspended solids content, dark color and offensive odor are of poor bacteriological standards.

Generally, domestic wastewater much lower in BOD and inorganic nutrient concentration, dilutes the slaughterhouse wastewater and makes it more amenable to biological treatment. The main disadvantage of sewer discharge is the surcharge imposed by municipalities to treat the wastewater.

1.1.2 Land application:

In land application, the biological material is directlyput into the land either by injection or by other mechanical means. The materials are biodegradable and provide nutrients to soils.In some countries due their temperature (too low), Canada for example, land application is notfeasible throughout year due to subfreezing temperatures.Thus, in most parts of Canada, considerable amount of wastewater would require to be stored during the winter months. Advantages of land application are (Masse´ and Masse´, 2000a):

(i) Recovery of wastes,

(ii) Replacement of chemical fertilizers (N, P, K), and

(iii) Soil structure improvements.

The limitations of land applications are:

(i) Public visual nuisance and odor,

(ii) Surface and groundwater pollution,

(iii) Soil, contamination due to toxic, heavy metals and organic compounds, and

(iv) Health hazards to human and animals due to pathogens.

Other environmental effects are: (i) acid and greenhouse gases emissions, and (ii) net primary energy consumption associated with treatment, storage and transportation.The advantages of the system are its simplicity and low cost. The disadvantages include possible surface and ground water contamination, odour problems, greenhouse gas emission, and soil pore clogging from excessive fat loads. Application on constructed wetlands could also be used as a polishing treatment for biologically treated wastewater(John 1995). Land application, however, is not practical in subfreezing temperatures, and in most parts of Canada large volumes of wastewater would have to be stored during the winter months.

1.1.3 Physico-chemical treatments:

Temperature and pH are two factors that determinethe pathogen content (Jones, 1999). Treatment of solids and sludge with temperatures greater than 45^{o}C (composting, heat treatment, and thermophilic digestion) can reduce the pathogens to non-detectable levels. Inactivation rates of organisms were found to double with a 10 ^{o}C rise in temperature and to increase with decrease in soil moisture.

Masse *et al*., (2005) mentioned that chambers, screens, settling tanks, and dissolved air flotation (DAF) widely units used for the removal of suspended solids, colloidal, and fats from slaughterhouse wastewater. In DAF units, air bubbles injected at the bottom of the tank transport light solids and hydrophobic material, such as fat and grease, to the surface where scum is periodically skimmed off. Blood coagulants (e.g. aluminium sulphate and ferric chloride) and or flocculants (polymers) are sometimes added to the wastewater in the DAF unit to increase protein flocculation and precipitation as well as fat flotation. Chemical DAF units can achieve COD reduction ranging from 32 to 90%, and are capable of removing large amounts of nutrients (Izumi *et al*., 2010). However, operational problems have been reported, and the system produces large volumes of putrefactive and bulky sludge that requires special handling and further treatment (Izumi *et al*., 2010). Fig. 1 showed the world oil and fat production in 1990 and 2011 (Chin, k. k. 1982).

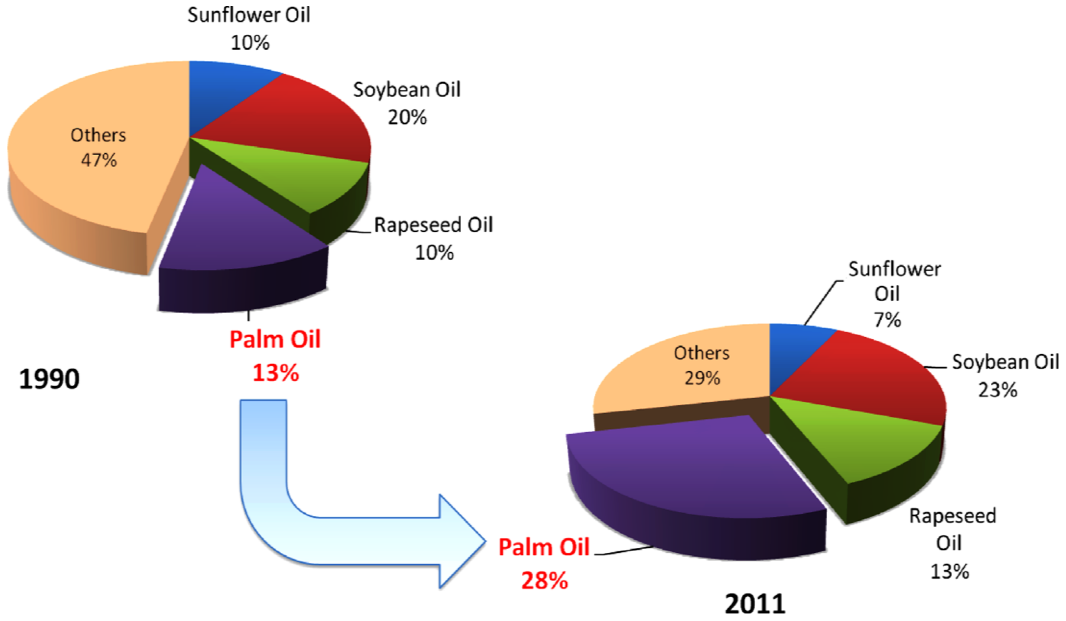

Fig. 1: World oil and fat production in 1990 and 2011 (Chin, k, 1982)

MATERIALS AND METHODS

With the increasing energy prices and the drive to reduce CO_2 emissions, universities and industries are challenged to find new technologies in order to reduce energy consumption, to meet legal requirements on emissions, and for cost reduction and increased quality. Slaughterhouse wastewater causes serious environmental pollution if directly discharged to the land due to its high chemical oxygen demand (COD), Total suspended solids (TSS) and biochemical oxygen demand (BOD). The conventional methodsusedfor slaughterhouse wastewater treatment have both economic and environmental disadvantages. The current study, ultrasonic membrane anaerobic system (UMAS) was used as a high separation, an alternative and cost effective method for treating slaughterhouse wastewater (to avoid membrane fouling).

The raw slaughterhouse wastewater was obtained from Indah Water Treatment Plant, Kuantan, Malaysia. The UMAS was used to treat the raw wastewater in a laboratory digester with an effective 200-litre volume. Figure 2presents a schematic design of the ultrasonic-membrane anaerobic system (UMAS).

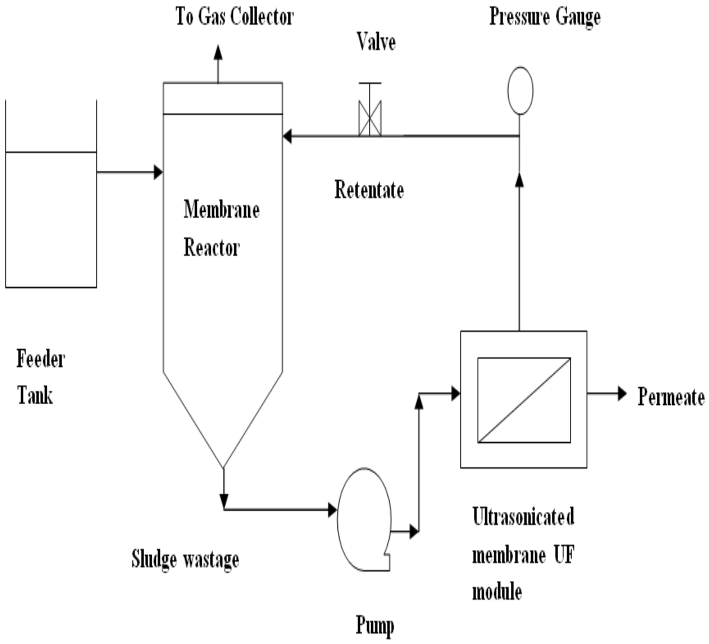

Fig.2: UMAS Design

2.1 Raw slaughterhouse wastewater:

The raw slaughterhouse wastewater samples used in this study were obtained from secondary municipal slaughterhouse treatment plant in Kuantan-Malaysia. The raw slaughterhouse was stored at 4°C prior to use. Samples were analysed for volatile suspended solids (VSS), biological oxygen demand (BOD), total suspended solids (TSS),chemical oxygen demand (COD) and pH.

2.2 Analytical methods:

Biogas volume was daily measured with water displacement, and methane content was analysed by J-Tube analyser and a gas chromatograph (GC 2011 Shimadzu) equipped with a thermal conductivity detector and a 2 m x3 mm stainless-steel column packed with Porapak Q (80/100 mesh). For the analysis of TS, VSS, VFA, alkalinity were determined according to the standard Methods (APHA, 2005). The chemical oxygen demand (COD) was measured using a Hach colorimetric digestion method (Method # 8000, Hach Company, Loveland, CO).

2.3Ultrasonic Membrane Anaerobic System (UMAS) operation:

The performance of ultrasonic membrane anaerobic system, UMAS was evaluated and results were shown in Table 4, with influent COD concentrations ranging from (8,000 to 25,400 mg/l) and organic loading rates (OLR) between (3.0 and 11 kg COD/m^3/d). In this investigation, the UMAS system was said to have achieved steady state when the operating parameters were within ± 10% of the average value. The produced biogas contained only CO_2 and CH_4, so the addition of sodium hydroxide solution (NaOH) or potassium hydroxide solution (KOH to absorb CO_2 effectively isolated methane gas (CH_4).Table 5 depicts results of the application of three known substrate utilization models.

Table 4: Summary of results (SS: steady state)

Steady State (SS)	1	2	3	4	5	6
COD feed, mg/L	8000	10700	15400	18700	20000	25400
COD permeate, mg/L	280	4286628609201321				
Gas production (L/d)	190.5	220	260	320	360373	
Total gas yield, L/g COD/d	0.210.320.480.54	0.62	0.68			
% Methane	7470.5	68.667.664.261.8				
Ch_4 yield, l/g COD/d	0.29	0.32	0.50	0.54	0.56	0.59
MLSS, mg/L	7800874010080112801254613620					
MLVSS, mg/L	5359	7428	8840	10340	11120	11424
% VSS	68.7184.99	87.7091.6788.6383.87				
HRT, d	308.660.313.910.86	9.64	8.7			
SRT, d	58029812726.813.4411.8					
OLR, kg COD/m^3/d	3.0	5.07.08.29.0	11			
SSUR, kg COD/kg VSS/d	0.164	0.195	0.2520.263	0.294	0.314	
SUR, kg COD/m^3/d	0.023	0.724	2.2254.576	5.685	7.347	
Percent COD removal (UMAS)	96.596.095.795.495.494.8					

Table 5: Results of the application of three known substrate utilisation models

Model	Equation	$R^2(\%)$
Monod	$U^{-1} = 2025\,S^{-1} + 3.61$ $K_s = 498$ $K = 0.350$ $\mu_{Max} = 0.284$	98.9
Contois	$U^{-1} = 0.306\ X\ S^{-1} + 2.78$ $B = 0.111$ $u_{Max} = 0.344$ $a = 0.115$ $\mu_{Max} = 0.377$ $K = 0.519$	97.8
Chen & Hashimoto	$U^{-1} = 0.0190\,S_o\ S^{-1} + 3.77$ $K = 0.006$ $a = 0.006$ $\mu_{Max} = 0.291$ $K = 0.374$	98.7

RESULTS AND DISCUSSION

3.1. The performance ultrasonic-membrane anaerobic system (UMAS):

The performance of the ultrasonic membrane anaerobic, UMAS was evaluated and summarized in Table 4.The UMAS performance was kept at different HRTs and influent COD concentrations. The selected models coefficients were derived from Eq. (2) in Table 5 by using a linear relationship; the coefficients are summarised in Table 5. At steady-state conditions with influent COD concentrations of 8,000-25,400 mg/l, UMAS performed well and the pH in the reactor remained within the optimal working range for anaerobic digesters (6.7-7.8). At the first steady-state, the MLSS concentration was about 7,800 mg/l whereas the MLVSS concentration was 5,329 mg/l, equivalent to 68.71% of the MLSS. This low result can be attributed to the high suspended solids contents in the slaughterhouse wastewater. At the sixth steady-state, however, the volatile suspended solids (VSS) fraction in the reactor increased to 88% of the MLSS. This indicates that the long SRT of UMAS facilitated the decomposition of the suspended solids and their subsequent conversion to methane (CH_4); this conclusion supported by (Abdurahmanet *al*., 2011) and (Nagano *et al*., 1992). The highest influent COD was recorded at the sixth steady-state (91,400 mg/l) and corresponded to an OLR of 9.5 kg COD/m^3/d. At this OLR the, UMAS achieved 96.7% COD removal and an effluent COD of 3000 mg/l. This value is better than those reported in other studies on anaerobic slaughterhouse wastewater digestion (Borja *et al*., 1993; Ng *et al*., 1985).The three kinetic models demonstrated a good relationship (R^2> 99%) for the membrane anaerobic system treating slaughterhouse wastewater, as shown in Figs. 3-5. The Contois and Chen & Hashimoto models performed better, implying that digester performance should consider organic loading rates. These two models suggested that the predicted permeate COD concentration (S) is a function of influent COD concentration (S_o). In Monod model, however, S is independent of S_o. The excellent fit of these three models (R^2> 97.8%) in this study suggests that the UMAS process is capable of handling sustained organic loads between 0.5 and 9.5 kg m^3/d.

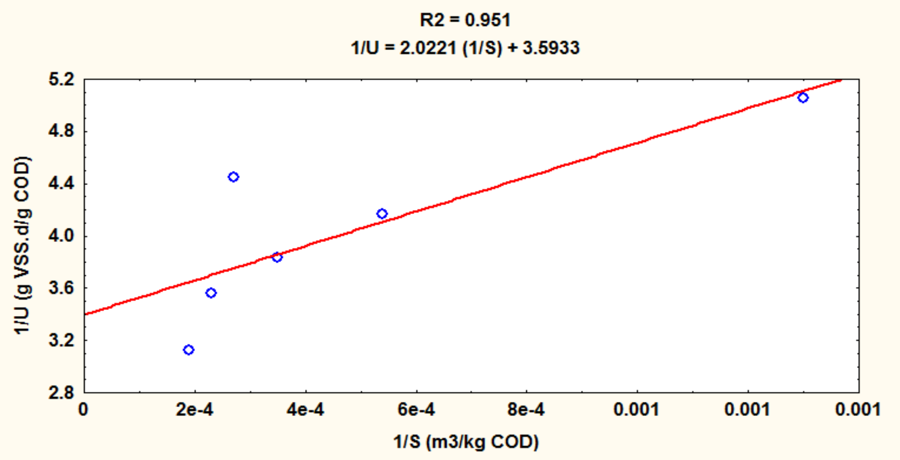

Fig.3: The Monod model

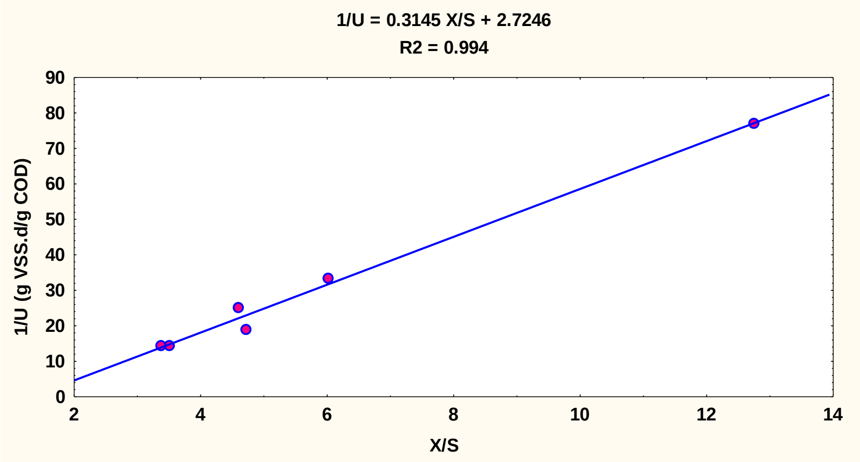

Fig.4: TheContois model

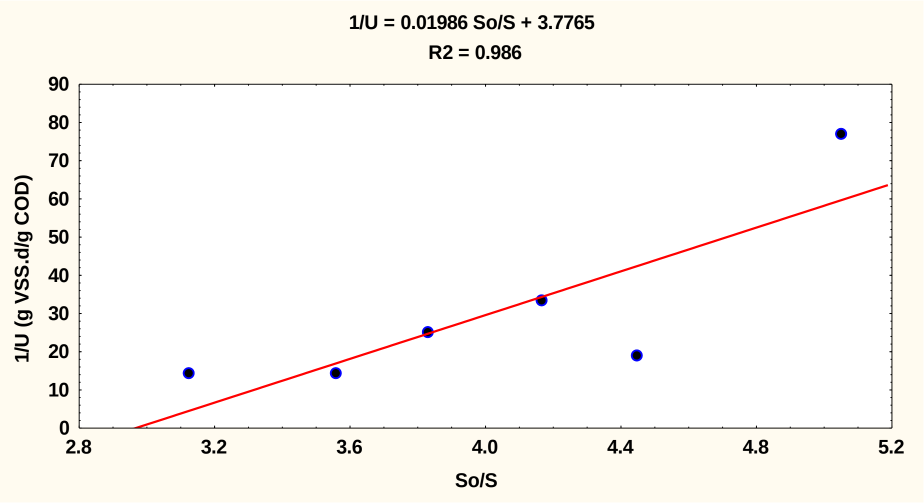

Fig.5: The Chen and Hashimoto model

Fig.6 shows the percentages of COD removed by UMAS at various HRTs. COD removal efficiency increased as HRT increased from 5.40 to 480.3 days and was in the range of 96.7 % - 98.5 %. This result was higher than the 85 % COD removal observed for slaughterhouse wastewater treatment using anaerobic fluidised bed reactors (Idris *et al*., 1998) and the 91.7-94.2 % removal observed for slaughterhouse wastewater treatment using MAS (Fakhru'l-Razi*et al*., 1999),and the 93.6-97.5% removal observed for POME treatment using MAS (Abdurahman*et al*., 2011). The efficiency of COD removal between HRTs of 480.3 days (98.5%) and 20.3 days (98.0%)did not differ significantly. On the other hand, the COD removal efficiency was reduced shorter HRTs; at HRT of 5.40 days, COD was reduced to 96.7 %. As shown in Table 2, this was largely a result of the washout phase of the reactor because the biomass concentration increased in the system. This may attributed due to the fact that at low HRT with high OLR, the organic matter was degraded to volatile fatty acids (VFA). The HRTs were mainly influenced by the ultra-filtration, UF membrane influx-rates which directly determined the volume of influent (POME) that can be fed to the reactor.

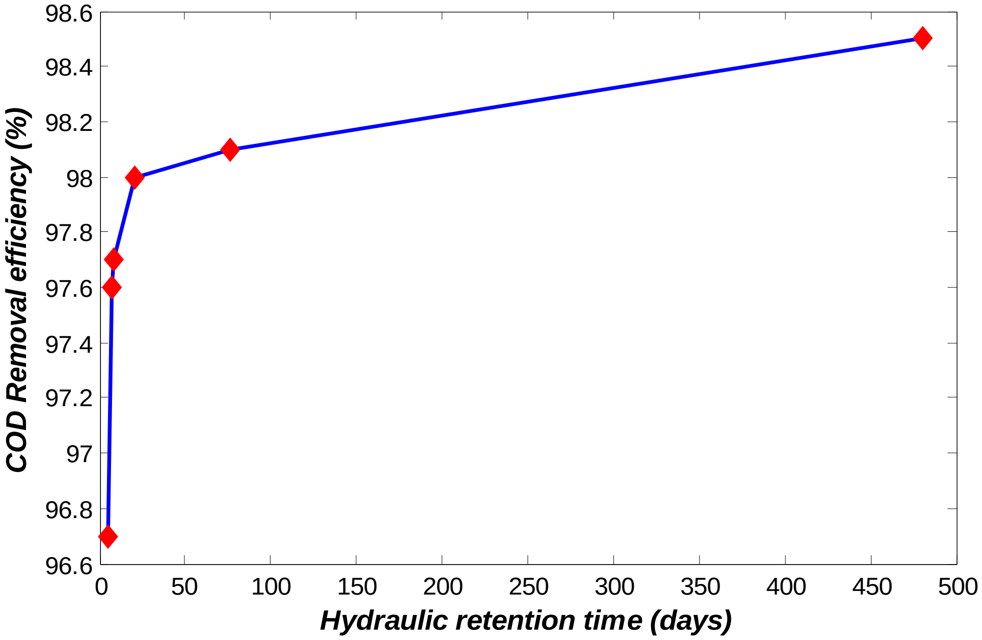

Fig.6: COD removal efficiency of UMAS vs. HRT

3.2 Determination of bio-kinetic coefficients:

The performance of UMAS experimental results in Table 4 was evaluated; kinetic coefficients were analysed and are summarised in Table 5. Substrate utilisation rates (SUR); and specific substrate utilisation rates (SSUR) were plotted versus OLRs and HRTs. Fig. 7 shows the SSUR values for COD at steady-state conditions HRTs between 5.40 and

480.3 days. SSURs for COD generally increased proportionally HRT declined, which indicated that the bacterial population in the UMAS multiplied (Wu *et al*., 2013). The bio-kinetic coefficients of growth yield (Y) and specific micro-organic decay rate, (b); and the K values were calculated from the slope and intercept as shown in Figs. 8 and 9. Maximum specific biomass growth rates (μ_{max}) were in the range between 0.248 and 0.474 d^{-1}. All of the kinetic coefficients that were calculated from the three models are summarised in Table 5. The small values of μ_{max} are suggestive of relatively high amounts of biomass in the UMAS (Zinatizadeh*et al*., 2006). According to (Grady *et al*., 1980), theμ_{max} and K values highly depend on both the organism and the substrate employed.

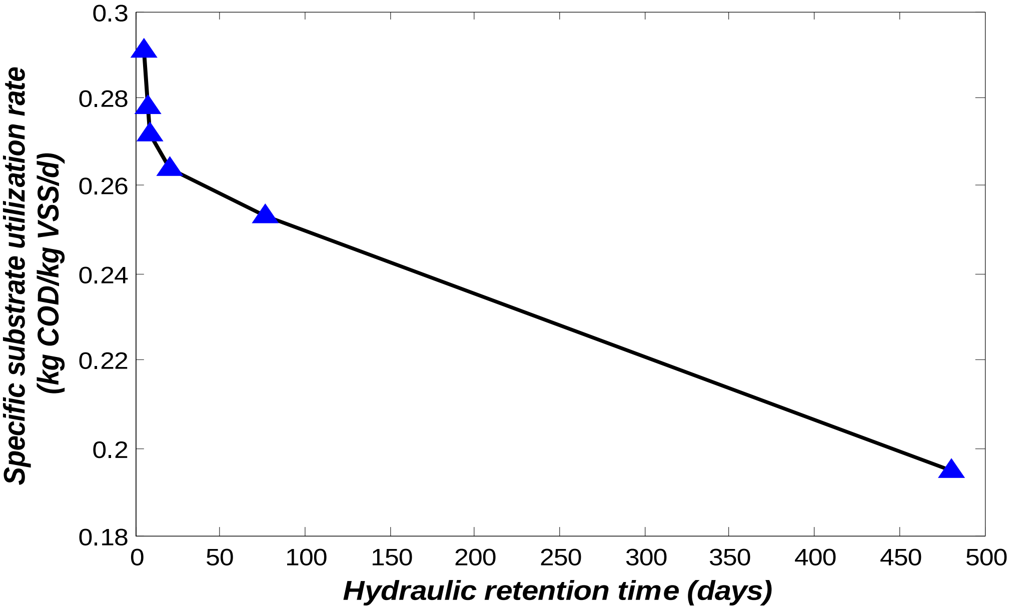

Fig.7: Specific substrate utilization rate vs. HRT

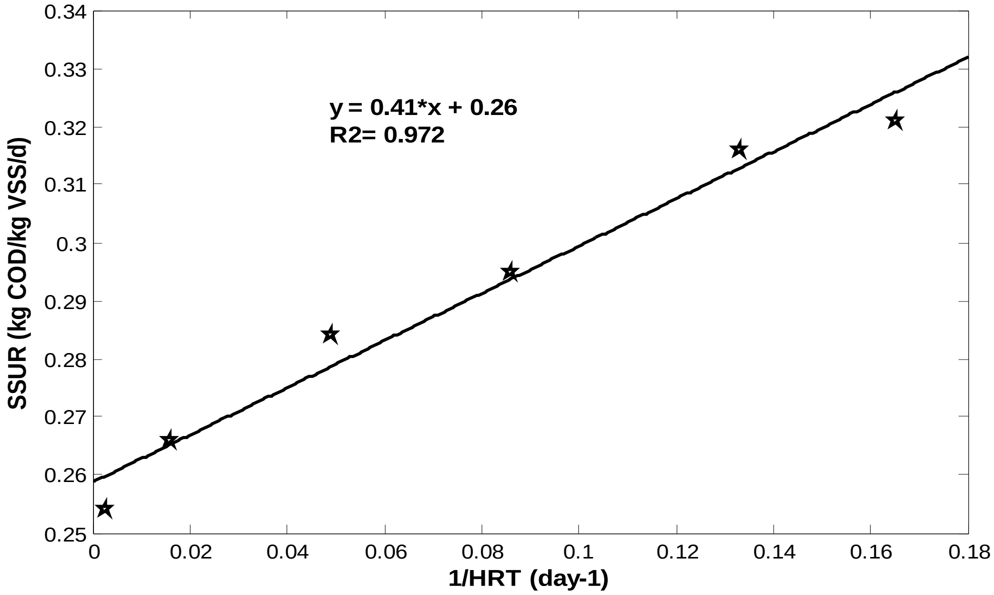

Fig.8: Determination of the growth yield, Y and the specific biomass decay rate, b

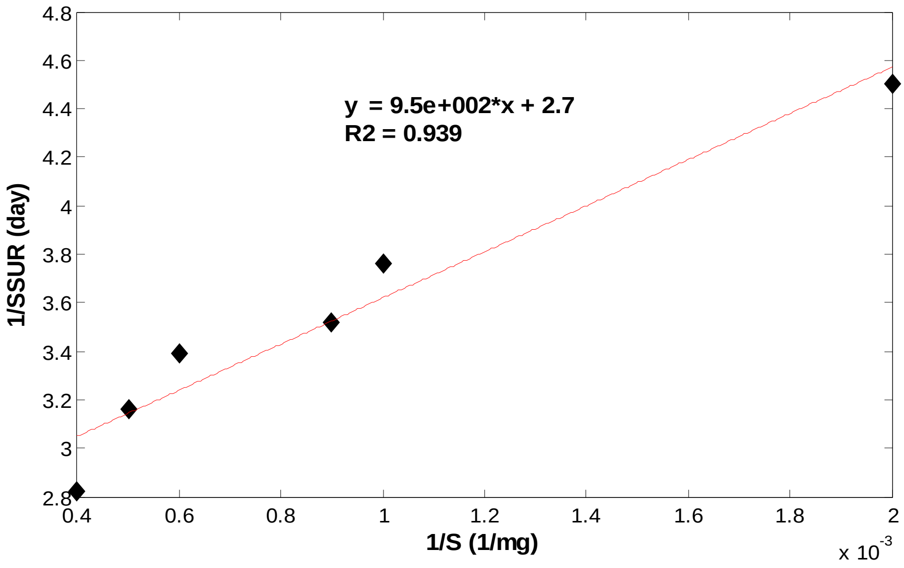

Fig.9: Determination of the maximum specific substrate utilization and the saturation constant, K

4.Production of methane (CH_4) and carbon dioxide (CO_2) gases:

To ensure the performance of anaerobic digesters treating adequately slaughterhouse wastewater and prevent failure, this study controlled several parameters such as pH, organic loading rates mixing rate. Therefore, the pH was maintained in an optimum range (6.8-7) to minimize the effects on methanogens that might biogas production. Because methanogenesis is also strongly affected by pH, methanogenic activity will decrease when the pH in the digester deviates from the optimum value. Mixing provides good contact between microbes and substrates, reduces the resistance to mass transfer, minimizes the build-up of inhibitory intermediates and stabilizes environmental conditions. This study adopted the mechanical mixing and biogas recirculation. Fig. 10 shows the gas production rate and the methane content of the biogas. The methane content generally declined with increasing OLRs. Methane gas contents ranged from 68.5% to 79% and the methane yield ranged from 0.29 to 0.59 CH_4/g COD/d. Biogas production increased with increasing OLRs from 0.29 l/g COD/d at 0.5 kg COD/m^3/d to 0.88 l/g COD/d at 9.5 kg COD/m^3/d. The decline in methane gas content may be attributed to the higher OLR, which favours the growth of acid forming bacteria over methanogenic bacteria. Thus the methane conversion process was adversely affected with reducing methane content and this has led to the formation of carbon dioxide at a higher rate. The gas production showed an increase from 277.8 to 580 Litres per day during the study. In this scenario, the higher rate of carbon dioxide; (CO_2) formation reduces the methane content of the biogas.

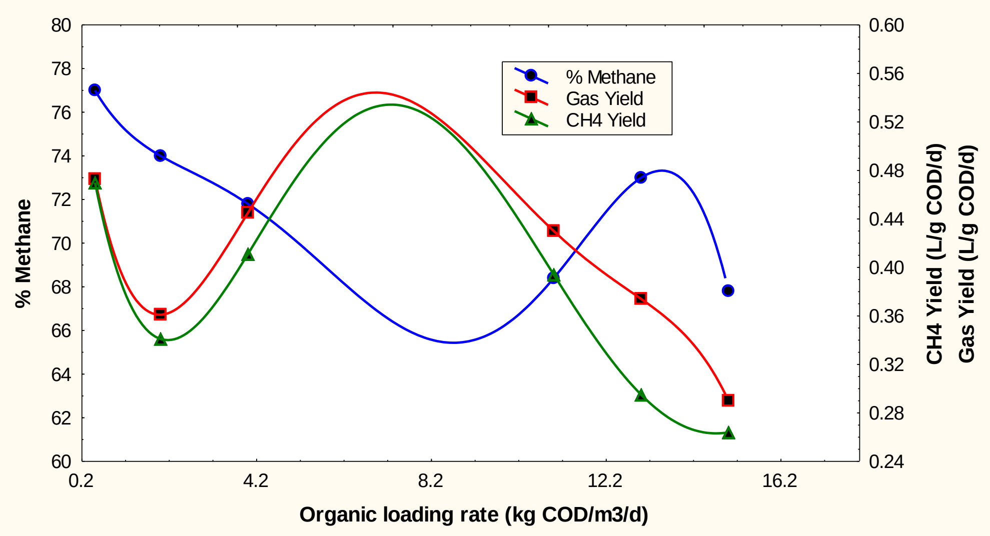

Fig.10: The produced gas and methane content

Conclusions:

Ultrasonic membrane anaerobic system, UMAS was investigated at three different kinetic models within a wide range of OLRs (3-11, kg COD/m^3/d). Based on the results, UMAS found to be adequate for the biological treatment of undiluted slaughterhouse wastewater. UMAS has retained 79% of methane gas and the overall substrate removal efficiency was very high, 98.5 %.

The removal efficiency of COD during the experiment was from 94.8 to 96.5% with hydraulic retention time, HRT from 308.6 to 8.7 days. The growth yield coefficient, Y was found to be 0.52gVSS/g COD the specific microorganism decay rate was 0.21 d^{-1} and the methane gas yield production rate was between 0.24 l/g COD/d and 0.56 l/g COD/d. Steady state influent COD concentrations increased from 16,560 mg/l in the first steady state to 40,350 mg/l in the sixth steady state.

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