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Biogas production from solid wastes removed from fish farm effluents

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Abstract – An experimental small scale partial recirculating system for rainbow trout was assembled. The system components were two 1.3-m^3 fish tanks with sloping bottoms, each connected to a sedimentation column and containing 50 kg rainbow trout biomass, an anaerobic up-flow digester (total volume 0.424 m^3, available volume 0.382 m^3) connected to the funnel shaped bottom of the sedimentation column by means of a peristaltic pump, an aerobic submerged plug-flow filter (total volume 1 m^3; filled with 0.83 m^3 plastic rings with a specific surface of 194 $m^2 \cdot m^{-3}$) and a submerged pump. Aeration was provided through porous stones. The anaerobic digester was filled with 35 mm cubes of expanded polyurethane foam (25 pores·cm^{-2}, specific surface 1.375 $m^2 \cdot m^{-3}$, filtering volume 0.291 m^3) and kept at a temperature of 24–25 °C using an electric heater. The gas chamber at the top of the anaerobic digester was connected to a gas meter and to an infrared continuous gas analyser. Measures on system performance with a recirculation rate of 60 % were done following three feeding levels (1, 1.5 and 2 % live weight). At the highest feeding rate, 2.8 L of faecal sludge collected from the trout tanks were pumped every four hours in the anaerobic digester. Slurry characteristic were: total N 0.197 $g \cdot L^{-1}$, TAN 0.014 $g \cdot L^{-1}$, volatile solids (VS) 16.91 $g \cdot L^{-1}$, suspended solids (SS) 21.39 $g \cdot L^{-1}$ and pH 6.9. Biogas production was 144 $L \cdot d^{-1}$ (mean value) with a methane content higher than 80 %. Methane volumetric production was 0.3 $m^3 \cdot m^{-3} \cdot d^{-1}$ and methane daily yield was 0.4 and 0.32 $m^3 \cdot kg^{-1}$ VS and SS respectively. After passing through the anaerobic digester, effluents were characterized by a total N content of 0.243 $g \cdot L^{-1}$, TAN 0.222 $g \cdot L^{-1}$, VS 1.1 $g \cdot L^{-1}$, SS 1.32 $g \cdot L^{-1}$ and pH 6.8. The anaerobic digester was able to significantly reduce VS and SS content of wastewater and the zeolite ion-exchange column significantly improved water quality of effluent produced by the digester. The aerobic biofilter significantly reduced the ammonia content of the water leaving the fish tanks. © Ifremer/Elsevier, Paris

Fish wastewater treatment / aerobic submerged plug-flow filter / anaerobic digester / biogas production / zeolite exchange column / rainbow trout

Résumé – Production de biogaz provenant des déchets solides d'un élevage de truites. Un système de recyclage semi-fermé a été réalisé sur une petite échelle pour l'élevage de la truite arc-en-ciel. Le système est composé de deux bacs d'élevage de 1,3 m^3 avec un fond incliné. Les bacs, contenant 50 kg de truites, sont reliés à deux colonnes de sédimentation, un réacteur anaérobie avec un flux ascendant (volume total 0,424 m^3, volume utilisable 0,382 m^3) alimenté par une pompe péristaltique qui est connectée à la base conique des colonnes de sédimentation, d'un filtre aérobie immergé (volume total 1 m^3, contenant 0,83 m^3 de matière plastique de remplissage, anneaux d'une surface spécifique de 194 $m^2 \cdot m^{-3}$) et d'une pompe immergée. L'aération est réalisée au travers de diffuseurs (pierres poreuses). Le réacteur anaérobie est rempli avec des cubes de 35 mm de mousse de polystyrène expansé (25 pores·cm^{-2}, surface spécifique 1,375 $m^2 \cdot m^{-3}$, volume filtrant 0,291 m^3) et la température est réglée à 24–25 °C par un système du chauffage. Le conduit de sortie du biogaz, placé sur le côté en haut du réacteur anaérobie, est connecté à un indicateur de débit du gaz et à un analyseur en continu à rayons infrarouges. Les analyses de rendement du système avec une recirculation d'eau de 60 % sont effectuées par rapport à trois niveaux d'alimentation (1, 1,5 et 2 % de poid vif). Lorsque le niveau d'alimentation est le plus fort (2 % de poids vif), le réacteur anaérobie est alimenté avec 2,8 L de déchets déposés au fond du bac toutes les 4 heures. Les caractéristiques chimiques de ces déchets sont : 0,197 $g \cdot L^{-1}$ d'azote total, 0,014 $g \cdot L^{-1}$ d'azote ammoniacal total, 16,91 $g \cdot L^{-1}$ de matières solides volatiles (VS), 21,39 $g \cdot L^{-1}$ de matières solides en suspension (SS), pH 6,9. La production volumétrique du méthane est de 0,3 $m^3 \cdot m^{-3} \cdot j^{-1}$ et les indices journaliers de conversion pour le méthane sont de 0,4 et 0,32 $m^3 \cdot kg^{-1}$ respectivement pour VS et SS. Les effluents du réacteur anaéorobie contenant 0,243 $g \cdot L^{-1}$ d'azote total, 0,222 $g \cdot L^{-1}$ d'azote ammoniacal total, 1,1 $g \cdot L^{-1}$ de solides volatiles, 1,32 $g \cdot L^{-1}$ de solides en suspension et pH 6,8. Le réacteur anaérobie est capable de réduire de façon significative le contenu de VS et SS dans les déchets, alors que la colonne à échange cationique de zéolites améliore de façon significative la qualité des effluents du réacteur anaérobie. Le filtre biologique aérobie réduit efficacement la concentration de l'ammoniaque de l'eau à la sortie des bacs d'élevage. © Ifremer/Elsevier, Paris

Traitement de l'eau / filtre aérobie / réacteur anaérobie / production du biogaz / colonne à échange cationique à zéolithes / truite arc-en-ciel

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1. INTRODUCTION

Traditional production practices for species of major commercial importance require large amounts of good quality water, a limited resource in many areas. The decline of clean water has shifted farms to high-density aquaculture with water re-use and recirculating systems. In these systems, fish are confined at a high density, and water is treated by several processes before it is recirculated to the culture units. The principal treatment processes used in recirculating plants are solids removal, ammonia oxidation, aeration and disinfection. Daily recycle rate can vary from 50–60 % to a maximum of 90 %; higher rates are impossible to reach as a daily partial water exchange is necessary to control nitrate, remove pollutants and replenish minerals and trace elements. Recirculating culture systems have been used for many years in marine aquariums, research, hatcheries and more recently commercial fish production. These systems are well suited especially for thermophilic species like eels [8, 10, 19, 21] and prawns [18], where there is the need to spare energy for maintaining the desired water temperature. In salmonid production, some recirculation systems have been used in hatcheries when a production goal is to be achieved and water availability is limited [11]. In trout farming, semiclosed systems appear to fit this species the best, satisfying water characteristics requirements, providing necessary pollution abatement and increasing culture density [7]. In all these plants, removed solids are allowed to settle in open sedimentation basins and after a variable period of time (from 6 months to 1 year) are spread on the fields as organic fertilizers. This system is cumbersome and costly as large concrete basins are required and moreover, the use as fertilizer can be limited by climatic conditions, soil quality and national regulations. Another possibility is offered by the anaerobic degradation of removed solids using the supernatant from the digestion basin to fuel nitrate removal by denitrifying organisms. This process was studied [23] but in that particular case, the authors limited their investigation to fish feed. Other researchers [1] considered anaerobic treatment of effluent and the use of volatile fatty acids released as fuel for the denitrifying activity. The use of solid wastes for anaerobic digestion and biogas production can represent a valid alternative as this technique can drastically reduce pollution in effluents water and at the same time, produce biogas whose methane content can be utilized for heating or electricity production. The literature on biogas production from cattle manure, piggery waste waters, by products of aquaculture, agroindustries and urban wastes is wide [3, 12, 14, 15, 17, 20] while no information was found on anaerobic digestion using solid wastes from fish plants. This trial was performed in order to evaluate the possibility of using solid wastes, removed from fish-farm effluents to produce biogas in a close system where water was partially recirculated.

2. MATERIALS AND METHODS

The recirculating system was composed of two fiber-glass cylindrical fish tanks (total volume 1.53 m^3, working volume 1.3 m^3) with funnel shaped bottom each equipped with a PVC sedimentation column (0.3 m internal diameter, 2 m height), an up-flow cylindrical anaerobic digester, connected to the sedimentation columns, a plug flow submerged biological filter and by a zeolite ion-exchange column connected to the anaerobic digester for final treatment of effluents (*figure 1*). A submerged centrifugal pump at the end of the tank containing the biological filter was used to carry water to the fish tanks. Recycle rate varied from 100 to 60 %, the exchange water being supplied from a well.

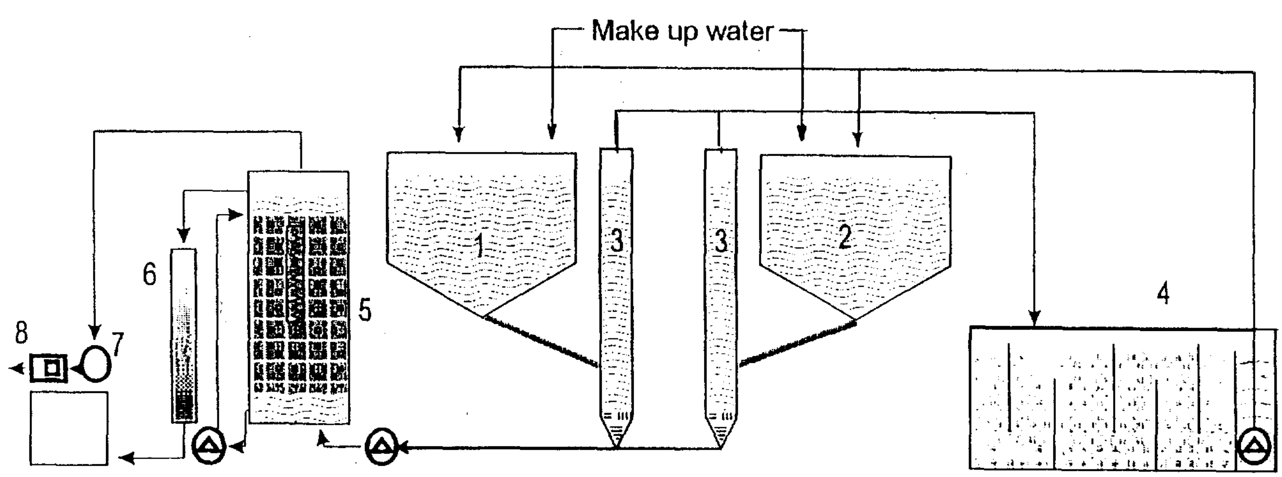

Figure 1. Scheme of the experimental recirculating plant: 1–2 fish tank; 3 sedimentation column; 4 aerobic biofilter; 5 anaerobic digester; 6 zeolite column; 7 gas flow-meter; 8 methane analyser.

Table I. Anaerobic digester and aerobic filter characteristics.

Parameters	Anaerobic digester	Aerobic filter
Type	Cylindrical random packed up-flow digester with adherent biomass	rectangular, plug-flow, submerged
Total volume (m^3)	0.424	1.18
Working available volume (m^3)	0.382	0.83
Volume of filter media (m^3)	0.291	0.83
Operating temperature (°C)	24–25	13–14
Filter media characteristics:		
1. Material	polyurethane cubes	PVC cylinders
2. Size (mm)	35	25 diameter × 30 height
4. Specific area ($m^2 \cdot m^{-3}$)	1 375	194
5. Void fraction (%)	–	0.86

2.1. Digester design

The up-flow anaerobic digester was made using a fibre-glass cylindrical tank (height 1.50 m, diameter 0.6 m) randomly packed with cubes in reticulated polyurethane and isolated with glass wool (*table I* contains details of the digester). Two perforated stainless steel plates were used to maintain the filtering media in the desired position. Psychrophilic conditions (24–25 °C) were assured by an electrical heater. A centrifugal pump mounted on the bottom of the digester assured an even temperature within the digester and content recirculation. Feed material coming from the two sedimentation columns was pumped by a peristaltic pump to the bottom of the cylinder. Biogas produced was collected by means of a plastic tube on the top of the digester and passed through a gas meter and a continuous infrared gas analyser.

2.2. Biological filter

The submerged plug flow biological filter was constructed in a rectangular fiber-glass tank with internal baffles and filled with a filter media comprising 2.5 cm diameter polyvinilchloride cylinders. Details of this filter are given in *table I*. Water mixing and oxygen addition were assured by air lift pumps. The biological filter received effluent water from the top of the two sedimentation columns. A submerged centrifugal pump situated at the end of the tank recirculated water to the fish tanks.

2.3. Zeolite ion-exchange column

The anaerobic digester effluent, was eluted through a column made from plastic tube (length 0.95 m, internal diameter 0.04 m) packed with natural zeolites (*table II*), in order to reduce its TAN (total ammonia nitrogen = $NH_3 + NH_4^+$) content. The saturated zeolites were replaced every three days.

2.4. Operation

Anaerobic digester was seeded three times with sludge from anaerobic digester of a domestic wastewater treatment plant. Each time 20 L of sludge were added. Aerobic filter was first inoculated with 100 mL of a mixed culture of bacteria (Sera-Nitrivec) and then fed a solution of ammonium chloride and ammonium sulphate to obtain an initial total ammonia nitrogen concentration of 2.9 $mg \cdot L^{-1}$. During the activation period, water was recirculated at a 100 % rate. Fish (230 rainbow trouts, 218 g average live weight, total biomass 50 kg) were transferred to the tanks when the biofilter became completely functional. Water recirculating rate was reduced to 60 % when fish were introduced in the tanks. Thereafter, recirculation was maintained at the same rate till the end of the trial. Fish were fed a commercial extruded diet at 1 % biomass-twice a day (at 9:00 h and 15:00 h). This feeding level was maintained until the whole plant worked properly and gas production was constant for several days. The duration of this period was four months. Thereafter, the 6-week experimental period took place. After two weeks, the feeding level was increased to 1.5 % biomass for two weeks and further increased to 2 % biomass for two more weeks. Chemical analysis were performed on influent and effluent water of aerobic biological filter (TAN, $N\text{-}NO_2$, $N\text{-}NO_3$, pH, DO), on influent and effluent slurry of anaerobic digester (pH, total N, TAN, TS, SS, VS) and on influent and effluent water of ion-exchange column (pH, total N, TAN, COD). pH was determined with a Gibertini laboratory pHmeter, dissolved oxygen by mean of an oxymeter (YSI), total ammonia nitrogen (TAN) according to Goltermann et al. [4], $N\text{-}NO_2$, $N\text{-}NO_3$, total solids (TS), volatile solids (VS), suspended solids (SS) and COD (dichromate reflux method) as previously described [2] and total N by means of the Kjeldhal

Table II. Characteristics of the zeolite ion-exchange column used for the TAN abatement in effluent leaving the anaerobic digester.

Parameters	Description
Type	Packed column
Total volume (L)	2.9
Zeolites characteristics:	
1. Type	clinoptilolite
2. Granular media size (mm)	2–3
3. Cationic exchange capacity ($meq \cdot 100\ g^{-1}$)	120–150
Ammonium ion retention ($g \cdot 100\ g^{-1}$)	2.6
Zeolite volume (L)	0.6
Zeolite weight (g)	610
Daily hydraulic load ($L \cdot d^{-1}$)	10–17

Table III. Effect of trout daily feeding allowance (1, 1.5, and 2 % of live weight) on chemical and physical characteristics of influent (I) and effluent (E) water in plug-flow aerobic filter subjected to a flow rate of 40 $L \cdot min^{-1}$ (means ± SD).

Feeding allowance	1		1.5		2	
Average fish weight (g)	507		541		585	
Daily feed allowance ($g \cdot d^{-1}$)	929.7		1 443.2		1 860.3	
	I	E	I	E	I	E
pH	7.76	7.75	7.73	7.71	7.65	7.60
TAN ($mg \cdot L^{-1}$)	0.63 ± 0.154	0.26 ± 0.117	1.05 ± 0.212	0.37 ± 0.111	1.05 ± 0.204	0.32 ± 0.106
TAN removal rate ($mg \cdot m^{-2} \cdot d^{-1}$)	130		230		260	
$N\text{-}NO_2$ ($mg \cdot L^{-1}$)	0.02 ± 0.005	0.04 ± 0.011	0.04 ± 0.010	0.07 ± 0.020	0.06 ± 0.013	0.09 ± 0.029
$N\text{-}NO_3$ ($mg \cdot L^{-1}$)	4.80 ± 0.097	5.21 ± 0.137	5.08 ± 0.063	5.66 ± 0.102	5.35 ± 0.124	6.19 ± 0.130
Dissolved oxygen ($mg \cdot L^{-1}$)	5.6	7.3	5.1	6.8	6.3	6.7

TAN: total ammonia nitrogen.

method. Water chemical and physical analyses were performed weekly during the initial period (four months) and during the experimental phase, while gas production and composition, and water temperature were measured daily. Influent and effluent water from the aerobic biofilter were further monitored at each feeding level for 24 h, sampling water every 2 h. The first analysis was performed at 10:00 h one hour after the first feeding.

3. RESULTS

No health problems were encountered during the trial and fish showed a good growth rate, reaching an average live weight of 585 g and a stocking rate of 35.8 $kg \cdot m^{-3}$ at the end of the trial. Water temperature varied slightly during the experiments (13.3–14.8 °C) and can be considered optimal for rainbow trout. In *table III*, data on characteristics of water entering and leaving the aerobic biofilter are reported. The hydraulic retention time was 18 min. TAN, $N\text{-}NO_2$ and $N\text{-}NO_3$ in effluent water increased as feeding level augmented from 1 to 1.5 % biomass without further increase when feeding rate reached 2 %. TAN level was significantly reduced by the biofilter and roughly 60–70 % of TAN was oxidized. At the same time $N\text{-}NO_2$ and $N\text{-}NO_3$ concentration increased as expected. Daily TAN removal rate for the unit of filtering media doubled (from 0.13 to 0.26 $g \cdot m^{-2} \cdot d^{-1}$) as feeding rate increased. The oxygen level in the effluent and influent water was always sufficient to assure the stoichiometric requirements for ammonia oxidation. In *table IV*, the composition of the faecal waste entering the digester and the liquid discharge are summarized. Faecal waste was characterized by high levels of total nitrogen, TAN and solids (TS, SS, VS) which increased following feeding rate increase. After passage through the anaerobic digester, faecal waste characteristics varied greatly as total N, and TAN increased significantly while total solids were reduced by 92 % and suspended solids and volatile solids by 93–97 %. The reduction in solids content took place irrespective of the feeding rate (*figure 2*). Daily biogas production (*table V*) increased with feeding rate from 49.8 to 78.8

Table IV. Effect of trout daily feeding allowance (1, 1.5, and 2 % of live weight) on chemical and physical caracteristics of influent (I) and effluent (E) water in up-flow anaerobic digester.

Feeding allowance	1		1.5		2	
	I	E	I	E	I	E
pH	6.9	6.9	6.9	6.8	6.9	6.8
Total nitrogen ($g \cdot L^{-1}$)	0.061	0.157	0.161	0.203	0.197	0.243
TAN ($mg \cdot L^{-1}$)	7.2	133.3	12.4	148.0	13.6	222.1
Total solids ($g \cdot L^{-1}$)	13.50	1.07	18.74	1.36	23.78	2.1
Soluble solids ($g \cdot L^{-1}$)	1.87	1.02	1.95	1.12	2.39	1.32
Suspended solids ($g \cdot L^{-1}$)	11.63	0.05	16.85	0.24	21.39	0.78
Volatile solids ($g \cdot L^{-1}$)	8.67	0.23	11.65	0.46	16.91	1.07
Fixed residue ($g \cdot L^{-1}$)	5.76	0.83	6.09	0.89	6.86	1.02

and 144.2 $L \cdot d^{-1}$ with a methane content of 80 % (*table V*). Volumetric CH_4 yield increased from 0.10 to 0.30 $L \cdot L^{-1} \cdot d^{-1}$ of digester following the increase of feeding level and consequently of volumetric load. Methane production ranged from 0.40 to 0.46 $L \cdot g^{-1}$ VS and from 0.31 to 0.32 $L \cdot g^{-1}$ SS, and was only slightly influenced by the amount of feed material entering the digester. The zeolite exchange column greatly reduced TAN and total N content of the liquid leaving the digester as 97–99 % TAN and 87–89 % total nitrogen

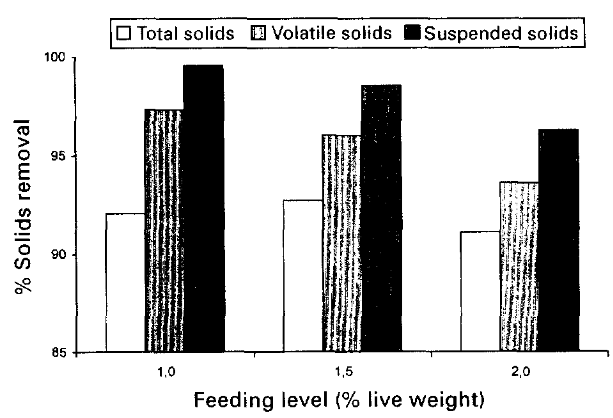

Figure 2. Total solids (TS), volatile solids (VS), and suspended solids (SS) removal (%) by the up-flow anaerobic digester at increasing feeding levels.

Table V. Effect of trout daily feeding allowance (1, 1.5, and 2 % of live weight) on operational data and biogas production from up-flow anaerobic digestor (means ± SD).

Feeding allowance	1	1.5	2
Hydraulic load ($L \cdot d^{-1}$)	10	12	17
Hydraulic retention time (d)	38	31	22
Biogas production ($L \cdot d^{-1}$)	49.8 ± 5.97	78.8 ± 6.06	144.2 ± 28.10
CH_4 content in biogas (%)	> 80	> 80	> 80
CH_4 production ($L^{-1} \cdot d^{-1}$)	39.84	63.04	115.36
CH_4 volumetric production ($L \cdot L^{-1} \cdot d^{-1}$)	0.10	0.16	0.30
Volumetric load:			
Volatile solids (VS) ($g \cdot L^{-1} \cdot d^{-1}$)	0.227	0.345	0.751
Suspended solids (SS) ($g \cdot L^{-1} \cdot d^{-1}$)	0.303	0.528	0.952
Methane yield			
($L \cdot gVS^{-1} \cdot d^{-1}$)	0.46	0.45	0.40
($L \cdot gSS^{-1} \cdot d^{-1}$)	0.34	0.31	0.32

Table VI. Effect of trout daily feeding allowance (1, 1.5, and 2 % of live weight) on chemical characteristic of influent (I) and effluent (E) water from ion-exchange column filled with zeolites.

Feeding allowance	1		1.5		2	
	I	E	I	E	I	E
Hydraulic load ($L \cdot d^{-1}$)	10		12		17	
TAN ($mg \cdot L^{-1}$)	133.3	0.8	148.0	3.3	222.1	6.1
Total Nitrogen ($mg \cdot L^{-1}$)	157	20	203	21	243	25
COD ($mg \cdot L^{-1}$)	340	289	605	390	1 063	589
pH	6.9	7.4	6.8	7.3	6.8	7.5

COD: chemical oxygen demand

were fixed by the zeolites which were less effective in reducing COD level (*table VI*).

4. DISCUSSION

With a water flow of 40 $L \cdot min^{-1}$ and a system working volume of 3.5 m^3, the turnover time was of 89 min while the new water turnover time, at a recirculating rate of 60 %, was 221 min. Other authors [7] obtained good performances with trouts reared in a semiclosed system with a new water turnover time of 9.2 h and a steady rate of fish biomass of 66 $kg \cdot m^{-3}$. Changes in water pH entering and leaving the biofilter were minimal either because of the limited recirculation rate (60 %) or because of the high total hardness of water (243 $mg \cdot L^{-1}$ as $CaCO_3$). The range of pH values can be considered optimal for a biofilter [6]. Undissociated ammonia level in water leaving fish tanks and entering the biofilter was always less then 0.01 $mg \cdot L^{-1}$. TAN entering biofilter increased with feeding rate as expected although the increase was not linear. The biofilter reduced TAN from 59 % to 64–70 % as TAN concentration increased resulting in effluent concentrations ranging from 0.26 to 0.37 $mg \cdot L^{-1}$. This removal rate can be considered satisfactory for a plug flow submerged stationary filter. Higher values have been reported [7] using a fluidized bed biofilter. TAN oxidation rates of filtering media increased from 0.13 to 0.26 $g \cdot m^{-2} \cdot d^{-1}$. These values compared favourably with those measured by other authors [19] on a recirculating system for eels with a bead filter or with a rotating bed contactor (56.2 and 256.7 $mg \cdot d^{-1} \cdot m^{-2}$ TAN removed). Nitrite concentration increased following the increase in feeding rate and during the passage to the aerobic biofilter. This effect appears difficult to explain as $N\text{-}NO_3$ concentration augmented noticeably in water leaving the aerobic biofilter thus indicating that the oxidation of $N\text{-}NO_2$ to $N\text{-}NO_3$ was not hindered by inhibitory factors [22].

The anaerobic digester demonstrated excellent SS and VS removal at all the feeding levels and at all the hydraulic retention times (HRT) tested. The mechanism of SS removal must involve a filtering system in the first step, followed by biodegradation and gasification. SS removal was higher than 99 % and showed a small drop (96 %) when the HRT decreased to 22 days and the amount of feed material increased with increasing feeding rate. Equal removal rates on an anaerobic filter for pig wastewater were noted in other trials [17]. The quality of the gas produced was stable over the duration of the investigation, a finding in agreement with those of other researchers [9]. The methane content of the gas was higher than 80 % and was not influenced by HRT. Similar data were observed in other experiments [17] and can be explained by the lack of coarse cellulose material. Other researchers [12, 14] using, dairy cattle manure as feed material, obtained a biogas with a significantly lower methane content (55–65 % and 38–51 % respectively).

Biogas and methane daily production increased as feeding rate and volumetric load increased. CH_4 volumetric production increased accordingly from 0.1 to 0.3 $L \cdot L^{-1}$ reactor volume following a trend already reported in other papers [20]. Higher yields per unit of volume of the digester were reported in literature [12–14] using an anaerobic digester of approx. 5-L volume. It is suggested that in this experiment, the reactor was probably oversized relative to the volumes required. Methane yield obtained from digested volatile solids ranged from 0.4 to 0.46 $L \cdot d^{-1}$. These results seem particularly high in comparison with the data reported by other investigators [14] who obtained a yield ranging from 0.05 to 0.18 $L \cdot g^{-1} \cdot d^{-1}$ VS added using a fixed film reactor fed dairy cattle manure. The good yield obtained in this investigation could be attributed to the characteristics of the waste used whose composition is probably closer to that of piggery waste as the data found in literature [17] (0.44 $L \cdot g^{-1}$ COD added) seem to indicate.

Clinoptilolite was effective in reducing TAN and total N levels in liquid discharged by the anaerobic digester. In a review [16] on the application of natural zeolites in aquaculture, the positive results obtained by several authors in reducing TAN content in freshwater fish farms following the use of naturally occurring ion exchange zeolite which are cheaply available have been underlined. Clinoptilolite is one such material and is highly selective for ammonium nitrogen. Moreover, ammonium uptake is maximized at high liquid flow rate with high and small zeolite particle size [5].

Part of these requirements were satisfied by the product used in this trial. The reduction in COD content must be attributed to the filtering capacity of the packed column. The pH increase in eluted water is a common positive secondary effect of natural zeolites.

In considering a possible practical use of this approach for handling suspended solids in effluent waters there are still many points to be elucidated and improved. First of all, a system for collecting faecal wastes from high flow rates has to be studied. In this experiment by using appropriate settling columns, most of the settleable and suspended solids have been collected. In large fish farms with large flow rates, suspended solids can be separated using microsieve filters but in this case a dewatering system is needed in order to increase the total dry matter (TDM) content of waste sludge from 0.5–1 $g{\cdot}L^{-1}$ to 20–23 $g{\cdot}L^{-1}$ as used in this trial. Secondly, the anaerobic digester and the whole auxiliary apparatus used need substantial improvement or a new layout of the digester has to be done and tested.

The third problem relates to biogas utilization. This can be used directly in a burner to produce thermal energy or, following depuration, can be employed as fuel in a cogeneration plant to obtain thermal and electrical or mechanical energy. When all these points are elucidated the minimum operational size of the digester can be calculated. From rough estimates, it can be said that to produce thermal energy, the minimal operational size of the digester should be between 50 and 70 m^3 of total capacity. Again from rough estimates, the fish biomass needed to produce sufficient faecal waste to feed the digester would vary from 22 to 30 t depending on the quality of the feed, the feeding management and the efficiency of the waste sludge collecting system. As can be seen from the previous paragraphs, at the moment the number of unknown variables involved is too high to estimate the cost of such a plant.

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