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Review Paper

Application of Upflow Anaerobic Sludge Blanket (UASB) Reactor Process for the Treatment of Dairy Wastewater – A Review

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ABSTRACT

The up flow anaerobic sludge blanket reactor for the treatment of dairy wastewater is often reported to be an effective method of treatment. The objective of this paper is to summarize recent research efforts and case studies in up flow anaerobic sludge blanket reactor for treating dairy effluents. The main characteristics of the dairy wastewater have been identified and the degradation mechanism of the primary constituents in dairy wastewaters, namely carbohydrates (mainly lactose), proteins and lipids has been described. Primary attention is focused on bench, pilot-scale up flow anaerobic sludge blanket reactor for the treatment of dairy wastewater effluents. Finally, areas where further research and attention are required have been identified.

INTRODUCTION

Among biological treatment processes, treatment by oxidation ponds, activated sludge plants and anaerobic treatment are commonly employed for dairy wastewater treatment (Bangsbo-Hansen 1985). The dairy industry is one of the largest sources of industrial effluents in Europe. A typical European dairy generates approximately 500m^3 of waste effluent daily. COD concentration of dairy effluents vary significantly, and moreover, dairy effluents are warm and strong, enabling them ideal for anaerobic treatment (Wheatley 1990). The dairy industry, like most other agro-industries, generates strong wastewaters characterized by high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) representing their high organic content (Orhon et al. 1993). Most of the wastewater volume generated in the dairy industry results from cleaning of transport lines and equipment between production cycles, cleaning of tank trucks, washing of milk silos and equipment malfunctions or operational errors (Kasapgil et al.1994, Danalewich et al.1998). Since dairy waste streams contain high concentration of organic matter, these effluents may cause serious problems, in terms of organic load on the local municipal sewage treatment systems (Perle et al. 1995).

Dairy wastewaters are treated using physico-chemical and biological treatment methods. However, since the chemical costs are high and the soluble COD removal is poor in physical-chemical treatment processes, biological processes are usually preferred (Vidal et al. 2000). In addition to environmental problems that can result from discharge of dairy wastewaters, introduction of products such as milk solids into waste streams also represents a loss of valuable product for the dairy facilities (Baskaran et al. 2003).

Furthermore, no requirement for aeration, low amount of excess sludge production and low area demand are additional advantages of anaerobic treatment processes, in comparison to aerobic processes. The aim of this paper is to summarize the recent research efforts and case studies in anaerobic treatment of dairy waste effluents. In the paper, the general characteristics of dairy waste streams are identified and the anaerobic degradation mechanisms of the main constituents of dairy wastewaters, namely carbohydrates, proteins and lipids, are explained. Anaerobic treatment practices of dairy wastewaters, as bench, pilot and full-scale efforts, are subsequently introduced overall in detail. Combined (anaerobic-aerobic) treatment systems for dairy wastewaters are also summarized briefly. Finally, areas where particular research and more attention required in the near future are identified.

General Characteristics of Dairy Wastewaters

Concentrations of suspended solids (SS) and volatile suspended solids (VSS) are also used to evaluate wastewater strength and treatability (Danalewich et al. 1998). Suspended solids in dairy wastewaters originate from coagulated milk, cheese curd fines or flavoring ingredients (Brown & Pico 1979). The inhibitory effects of lipids in anaerobic processes can mainly be correlated to the presence of long chain fatty acids (LCFAs), which cause retardation in methane production (Hanaki et al. 1981).

While, LCFAs were particularly reported to be inhibitory to methanogenic bacteria (Koster 1987), difficulties experienced with the presence of lipids in anaerobic treatment processes have been previously reported in literature (Sayed et al. 1988, Rinzema et al. 1993, Alves et al. 1997, Alves et al. 2001). Lipids are potentially inhibitory compounds, which can always be encountered during anaerobic treatment of dairy wastewaters.

There is little information available in literature about the anaerobic digestibility of lipids. During anaerobic degradation, lipid is firstly hydrolyzed to glycerol and long chain fatty acids, followed by β-oxidation, producing acetate and hydrogen (McInerney1988). Anaerobic fermentation of lactose yields organic acids, namely acetate, propionate, iso- and normal-butyrate, iso and normal valerate, caproate, lactate, formate and ethanol (Kissalita et al. 1990). Two possible carbon flow schemes were proposed for acidogenic fermentation of lactose, carbon flow from pyruvate to butyrate and lactate, both occurring in parallel (Kissalita et al. 1989).

Lipids do not cause serious problems in aerobic processes; however, they sometimes affect conventional single-phase anaerobic treatment processes adversely (Hanaki et al. 1990, Komatsu et al.1991). Anaerobic degradation of proteins and the effects of ammonia on this mechanism were recently investigated in detail (Pavlostathis & Giraldo-Gomez 1991, Gallert et al.1998). Unsaturated LCFAs seemed to have a greater inhibitory effect than saturated LCFAs. Unsaturated LCFAs strongly inhibited methane production from acetate and moderately inhibited β-oxidation. Thus, unsaturated LCFAs should be saturated to prevent lipid inhibition in anaerobic processes (Komatsu & Hanaki 1991). Lactose is the main carbohydrate in dairy wastewater and is a readily available substrate for anaerobic bacteria.

Anaerobic methanation of lactose needs a cooperative biological activity from acidogens, acetogens and methanogens (Yu & Pinder 1993). The use of acid and alkaline cleaners and sanitizers in the dairy industry additionally influences wastewater characteristics and typically results in a highly variable pH (Kasapgil et al.1994, Danalewich et al. 1998, Demirel & Yenigun 2004). Casein is the major protein in milk composition and in dairy effluents. When fed to acclimated anaerobic reactors, degradation of casein is very fast and the degradation products are non-inhibitory (Perle et al. 1995). Wastewaters from the dairy industry are usually generated in an intermittent way, so the flow rates of these effluents change significantly.

High seasonal variations are also encountered frequently and correlate with the volume of milk received for processing; which is typically high in summer and low in winter months (Kolarski & Nyhuis 1995). The biodegradation of lipids is difficult due to their low bioavailability (Petruy & Lettinga 1997). As stated above, dairy wastewater is composed of easily degradable carbohydrates, mainly lactose, as well as less biodegradable proteins and lipids (Fang & Yu 2000). High COD

Table 1: Characteristics of dairy waste effluents.

Effluent Type	COD (mg/L)	BOD (mg/L)	pH (units)	Alk. (as Ca CO_3) (mg/L)	Suspended solids (mg/L)	Volatile S.S. (mg/L)	Total solids (mg/L)	TKN (mg/L)	Total phosphorus (mg/L)	Reference
Creamery	2000-6000	1200-4000	8-11	150-300	350-1000	330-940	-	50-60	-	Kasapgil et al. 1994
Not given	980-7500	680-4500	-	-	300	-	-	-	-	Kolarski & Nyhuis 1995
Mixed dairy	1150-9200	-	6-11	320-970	340-1730	255-830	2705-3715	14-272	8-68	Demirel 2003
Processing Cheese Whey	68814*	-	-	-	-	-	-	1462*	379*	Malaspina et al. 1995
Cheese	1000-7500	588-5000	5.5-9.5	-	500-2500	-	-	-	-	Monroy et al. 1995
Fresh milk	46568*	-	6.92*	-	-	-	-	-	-	Strydom et al. 1977
Cheese	5340*	-	5.22*	-	-	-	-	-	-	Strydom et al. 1977
Milk powder butter	1908*	-	5.80*	-	-	-	-	-	-	Strydom et al. 1977
Mixed dairy processing	63100*	-	3.25*	-	12500*	12100*	53000*	-	-	Hwang & Hansen 1998
Cheese Whey	61000*	-	-	-	1780*	1560*		980*	510*	Vanden & Kennedy 1992
Cheese	-	-	4.7*	-	2500*	-	-	830*	280*	Gavala et al. 1999
Not given	-	-	4.4-9.4	-	90-450	-	-	-	-	Eroglu et al. 1991
Fluid milk	950-2400	500-1300	5.0-9.5	-	90-450	-	-	-	-	Oztuk et al. 1993

*Mean concentrations are reported.

Table 2: Concentrations of selected elements in dairy wastewaters.

Effluent Type	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Co (mg/L)	Ni (mg/L)	Mn (mg/L)	Reference
Creamery	170-200	35-40	35-40	5-8	2-5	0.05-0.15	0.5-1.0	0.02-0.10	Rasapgil et al. 1994
Cheese/whey	735*	42.8*	47.7*	11.4*	-	-	-	-	Danalewich et al. 1998
Cheese/alcohol	423*	41.2*	54.3*	8.3*	-	-	-	-	Danalewich et al. 1998
Cheese/beverage	453*	8.6*	33.6*	16.9*	-	-	-	-	Danalewich et al. 1998
Cheese/whey	419*	35.8*	52.3*	11.0*	-	-	-	-	Danalewich et al. 1998
Mixed dairy	123-2324	8-160	12-120	2-97	0.5-6.7	0	0-0.13	0.03-0.43	Demirel 2003
Cheese	720-980	-	530-950	-	-	-	-	-	Money et al. 1995

*Mean concentrations are reported.

Table:3: Typical operating conditions for anaerobic digesters.

Anaerobic digester configuration	Load (kg COD/(m3 day))	Retention	COD removal (%)
CSTR	0.5-2.5	1-5 days	80-90
Anaerobic filter	2-10	10-50 h	70-80
UASB	2-15	8-50 h	70-90
Fluidized bed	2-50	0.5-24 h	70-80

concentrations indicate that dairy industry wastewaters are strong and fluctuating in nature. Significant fractions of the organic components and nutrients in dairy waste streams are derived from milk and milk products.

In industrial dairy wastewaters, nitrogen originates mainly from milk proteins, and is present in various forms; either an organic nitrogen (proteins, urea, nucleic acids), or as ions such as NH_4^+, NO_2^- and NO_3^-. Phosphorus is found mainly in inorganic forms; as orthophosphate (PO_4^{3-}) and poly-phosphate ($P_2O_7^{4-}$), as well as organic forms (Guillen-Jimenez et al. 2000). In cheese-processing wastewater, 97.7% of total COD is accounted for by lactose, lactate, protein and fat (Hwangs & Hansen 1998). Thus, dairy wastewater can easily be defined as a complex type of substrate (Fang & Yu 2000, Angelidaki 1999, Yu & Fang 2000). A summary of data obtained from literature for general properties of dairy waste effluents from full-scale operations is given in Table 1.

Concentrations of selected elements, namely sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), cobalt (Co), nickel (Ni) and manganese (Mn) are also given in Table 2. Particularly high Na concentrations point out the use of large amount of alkaline cleaners in dairy plants. The concentrations of heavy metals, such as copper (Cu), nickel (Ni) and zinc (Zn) were reported to be in a range that would not affect adversely the performance of a biological treatment step (Danalewich et al. 2003).

Conventional (Single-Phase) Anaerobic Treatment of Dairy Effluents

At an OLR of 8.5 g COD/day and an HRT of 5 h, 87% COD removal was achieved at 30°C. Another laboratory-scale investigation pointed out that more than 97% COD reduction could be achieved in a UASB reactor during anaerobic treatment of cheese whey (Yan et al. 1989).

Methanol addition during start-up of UASB reactors treating a dairy waste from raw ice-cream production facility provided rapid granulation of biomass and enhanced the settling velocity and specific activity of the sludge (Cayless et al. 1990). However, methanol addition also resulted in severe biomass wash-out from the system. During laboratory-scale anaerobic digestion of cheese whey, increased substrate loadings led to the failure of the UASB reactor, in a range of influent substrate concentration from 4.5 to 38.1 g COD/L, at an HRT of 5 days (Yan et al. 1990). Anaerobic treatment of cheese-production wastewater using a laboratory-scale UASB reactor provided a COD removal of about 90%, at an OLR of 31g COD/day (Rico Gutierrez et al. 1991). Furthermore, OLR peaks above 45 g COD/day yielded a COD reduction between 70 and 80%. Sudden increase in the OLR was accompanied by biomass granulation, resulting in a more stable reactor operation during waste treatment.

The kinetic model and the kinetic coefficients of laboratory-scale continuous UASB reactors treating whey permeate were determined, in an HRT range between 0.4 and 5 days and at a constant influent substrate concentration of 10.4 ± 0.2 g COD/L (Hwang & Hansen 1992).

The maximum substrate utilization rate *(k),* half saturation coefficient (K_L), yield coefficient (Y) and decay rate coefficient (K_d) were determined to be 0.941, 0.773 kg

COD/(kg VSS day), 0.153 kg VSS/(kg COD) and 0.022 day^{-1}, respectively. Under the same HRT and influent substrate concentration, COD removal efficiency in the UASB reactor ranged between 64.2 and 99 %. Higher than 90% of COD removal could be attained, with an OLR maintained around 5-6 kg COD/(m^3 day). Moreover, the fat content in dairy wastewater could successfully be degraded by the anaerobic filter reactor.

Up flow anaerobic sludge blanket (UASB) reactors have been successfully employed for dairy wastewater treatment in full-scale applications for almost two decades (Malina et al. 1992). COD removal rates varied between 85 and 99%, at an HRT of 6 days and in an OLR range from 2 to 7.3 g COD/day, while removal rates were around 81% in an HRT range between 30 and 40 days.

Anaerobic treatability studies of dairy effluents from a large integrated industry processing milk were carried out using a laboratory-scale hybrid UASB reactor (Ozturk et al. 1993). The anaerobic digestion of cheese whey was investigated, in terms of instability caused by the strength of the influent in a UASB reactor (Yan et al. 1993). Biological treatment of a cheese-producing wastewater by a laboratory-scale UASB reactor was reported for influent wastewater concentrations between 12 and 60 g COD/L (Gavala et al. 1999). The IC reactor system is able to handle high up flow liquid and gas velocities, which enables treatment of low strength wastes at short HRTs, as well as treatment of high-strength effluents at very high volumetric loading rates feasible. Recently, feasibility of using UASB reactors for dairy wastewater treatment was explored by operating two types of UASB reactors (Ramasamy et al. 2004).

Two-Phase Anaerobic Treatment of Dairy Wastewater

Actually, numerous studies have been performed covering particularly the anaerobic acidogenesis of dairy wastewaters. Initially, acidogenesis of lactose was investigated extensively in laboratory-scale studies, mostly focusing on the degradation kinetics of lactose (Kissalita et al. 2000). High influent substrate concentrations, fluctuations in dairy wastewater flow rate and composition, excessive suspended solids and lipid concentrations in dairy effluents, the presence of sufficient amount of alkalinity in anaerobic digesters and appropriate anaerobic reactor configuration employed for treatment are common factors that affect maximum loading rates and expected treatment efficiencies (Yan et al. 1990, Rico Gutierrez et al. 1991, Kasapgil et al. 1994, Strydom 1994).

Biomass granulation must definitely be achieved for stable and satisfactory UASB reactor operation and finally, sufficient amount of alkalinity is frequently discussed to be the most important factor for controlling process reliability during anaerobic treatment of dairy wastewater (Rico Gutierrez et al. 1991). For the cheese factory effluent, 97% COD removal was achieved at an OLR of 2.82 kg COD/(m^3 day), while at an OLR of 2.44 kg COD/(m^3 day), 94% COD removal was obtained for the fresh milk effluent. For the powder milk/butter factory effluent, 91% COD removal was achieved at an OLR of 0.97 kg COD/(m^3 day).

In addition to these works, the operating criteria for pre-acidification of dairy wastewater obtained from a milk and cream bottling plant were determined in a laboratory-scale CSTR (Ince et al. 1995). Studies covering the acid phase digestion of industrial and synthetic dairy wastewaters have been reviewed in different aspects previously in this paper (Hwang & Hansen 1998, Hwang et al. 2003). Two-phase anaerobic treatment systems are particularly suitable for wastewaters containing high concentrations of organic suspended solids, such as food and agricultural industry wastewaters (Guerrero et al. 1999). In an influent substrate concentration range between 2 and 30 g COD/L and at 55°C, carbohydrate degraded under all conditions, however, protein and lipid conversions both decreased when the substrate concentration increased.

The major acidogenesis products were measured to be acetate, propionate, butyrate and ethanol. Acidification of mid-and high-strength synthetic dairy wastewaters were studied in a laboratory-scale up flow reactor (Yu & Fang 2001).

The authors reported that the high-strength wastewater favoured production of hydrogen (H_2) and alcohols. Inhibitory effects of zinc (Zn) and copper (Cu) on anaerobic acidogenesis of dairy wastewater were investigated in a laboratory-scale study (Yu & Fang 2001). The authors concluded that copper seemed more toxic than zinc to the overall production of VFAs and hydrogen in the acidogenic reactor. Start-up of two acidogenic reactors under mesophilic (37 °C) and thermophilic (55°C) conditions were compared using a methanogenic granular sludge and dairy wastewater. It took more than 2 months to establish a microbial community with a stable metabolic activity. Acidogenesis of synthetic dairy wastewater was also studied at a pH range between 4.0 and 6.5, in a laboratory-scale up flow reactor at 37°C. At an HRT of 12 h and a pH of 5.5, 95% of carbohydrates, 82% of proteins and 41% of lipids could be degraded in the acid phase reactor. Moreover, batch reactors were used to investigate the thermophilic anaerobic acidification of a synthetic dairy wastewater at a pH of 5.5. According to the authors, hydrogen production could be attributed to the fermentation of carbohydrate.

Two acidogenic up flow reactors were operated under mesophilic (37°C) and thermophilic (55°C) conditions with a synthetic dairy wastewater, in order to compare the effects of temperature on the performances of both reactors. Almost no difference was reported for the performances of both reactors in terms of COD removal and degree of acidification, at any given OLR.

A cheese-processing wastewater was used to determine the biokinetics of mesophilic acidogens (Yu et al.2002). At a pH of 7 and 36.2°C, the maximum microbial growth rate (μ_{max}), half saturation coefficient *(K_s),* the microbial yield coefficient (Y) and microbial decay rate (kd) were computed to be 9.9 per day, 134 mg COD/L, 0.29 mg MVSS/ mg COD and 0.14 per day, respectively. While at a pH of 7.3 and 36.2°C, μ_{max}, K_s, Y and k_d were determined to be 9.3 per day, 482.5mg COD/L, 0.20 mg MVSS/mg COD and 0.25 per day, respectively. In a more recent study, the effects of HRT between 12 and 24 h on anaerobic acidogenesis of dairy wastewater was investigated using a laboratory-scale continuous-flow completely mixed anaerobic reactor with solids recycle (Demirel & Yenigun 2004).

Typical operating conditions for anaerobic digesters are outlined in Table 3. Treatment of dairy wastewater using UASB reactors operated in an intermittent mode, improved the efficiency of the biological conversion by reducing the accumulation of organic matter in the sludge bed through a higher methanization with a high feedless period. In addition, it was possible to attain higher loads with the intermittent operation as compared with continuous system (Coelho et al. 2006).

CONCLUSION

Conventional up flow anaerobic sludge blanket (UASB) reactors are often used for treating dairy wastewater. In fact the UASB reactor are suitable for treating food industry wastewaters, since they can treat large volume of wastewaters in a relatively short period of time. Removal of nitrogen and phosphorus from diary wastewater has recently gained significant attention due to more strict environmental regulations, so current research efforts clearly seem to focus on nutrient removal from dairy waste effluents is worth investigating.

REFERENCES

Alves, M.M., Alvares Pereira, R.M., Mota Vieira, J.A. and Mota, M. 1997. Effect of lipids on biomass development in anaerobic fixed-bed reactors treating a synthetic dairy waste. In: Proceedings of the International Symposium of Environmental Technology, pp. 521-524.

Alves, M.M., Mota Vieira, J.A., Alvares Pereira, R.M. and Mota, M. 2001. Effect of lipids and oleic acid on biomass development in anaerobic fixed-bed reactors. Part 1. Biofilm growth and activity. Water Res., 35: 255-263.

Angelidaki, I., Ellegaard, L. and Ahring, B.K. 1999. Comprehensive model of anaerobic bioconversion of complex substrates to biogas. Biotechnol. Bioeng., 63: 363-72.

Anonymous 1992. Biogas technology in the Netherlands, anaerobic waste and wastewater treatment with energy production. In: Malina, J.F. and Pohland, F.G. (eds.) Design of Anaerobic Processes for the Treatment of Industrial and Municipal Wastes. Technomic Pub-lishing Company, Pennsylvania, pp. 119-120.

Bangsbo-Hansen, D.I. 1985. Treatment of dairy wastewater in the developing countries-The Danish experience. Ind. Environ., 8: 10-12.

Baskaran, K., Palmowski, L.M. and Watson, B.M. 2003. Wastewater reuse and treatment options for the dairy industry. Water Sci. Technol., 3: 85-91.

Brown, H.B. and Pico, R.F. 1979. Characterization and treatment of dairy wastes in the municipal treatment system. In: Proceedings of 34th Purdue Industrial Waste Conference, pp. 326-334.

Cayless, S.M., daMotta Marques, D.M.L. and Lester, J.N. 1990. A study of the effects of methanol in start-up of UASB reactors. Biol. Wastes, 31: 123-35.

Coelho, N.M, Rodrigues, A.A., Arroja, L.M. and Capela, I.F. 2006. Effect of non-feeding period length on the intermittent operation of UASB reactors treating dairy effluents. Biotechnology and Bioengineering 96: 244-249.

Danalewich, J.R., Papagiannis, T.G., Belyea, R.L., Tumbleson, M.E. and Raskin, L. 1998. Characterization of dairy waste streams, current treatment prac-tices and potential for biological nutrient removal. Water Res, 32: 3555-3568.

Demirel, B. 2003. Acidogenesis in Two-Phase Anaerobic Treatment of Dairy Wastewater. Ph.D. Thesis. Bogazici University, Istabul, Turkey.

Demirel, B. and Yenigun, O. 2004. Anaerobic acidogenesis of dairy wastewater: The effects of variations in hydraulic retention time with no pH control. J. Chem. Technol. Biotechnol., 79: 755-60.

Eroglu, V., Ozturk, I., Demir, I., Akca, L. and Alp, K. 1991. Sequencing batch and hybrid anaerobic reactors treatment of dairy wastes. In: Proceedings of 46th Purdue Industrial Waste Conference, pp. 413-422.

Fang, H.H.P. and Yu, H.Q. 2000. Effect of HRT on mesophilic acidogenesis of dairy wastewater. J. Environ. Engg., 126: 1145-1148.

Gallert, C., Bauer, S. and Winter, J. 1998. Effect of ammonia on the anaerobic degradation of protein by a mesophilic and thermophilic biowaste population. Appl. Microbiol. Biotechnol., 50: 495-501.

Gavala, H.N., Kopsinis, H., Skiadas, I.V., Stamatelatou, K. and Lyberatos, G.L. 1999. Treatment of dairy wastewater using an upflow anaerobic sludge blanket reactor. J. Agric. Eng. Res. 73: 59-63.

Guerrero, L., Omil, F., Mendez, R. and Lema, J.M. 1999. Anaerobic hydrolysis and acidogenesis of wastewaters from food industries with high content of organic solids and protein. Water Res., 33: 3281-3290.

Guillen-Jimenez, E., Alvarez-Mateos, P., Romero-Guzman, F. and Pereda-Martin, J. 2000. Bio-mineralization of organic matter as affected by pH. The evolution of ammonium and phosphates. Water Res., 34: 1215-1224.

Hanaki, K., Matsuo, T. and Kumazaki, K. 1990. Treatment of oily cafeteria wastewater by single-phase and two-phase anaerobic filter. Water Sci. Technol., 22: 299-306.

Hanaki, K., Matsuo, T. and Nagase, M. 1981. Mechanism of inhibition caused by long-chain fatty acids in anaerobic digestion process. Biotechnol. Bioeng., 23: 1591-1610.

Hwang, S. and Hansen, C.L. 1998. Characterization of and bioproduction of short-chain organic acids from mixed dairy-processing wastewater. Trans Am. Soc. Agric. Eng. 41: 795-802.

Hwang, S.H. and Hansen, C.L. 1992. Biokinetics of an upflow anaerobic sludge blanket reactor treating whey permeate. Bioresour. Technol., 41: 223-230.

Ince, O., Anderson, G.K. and Kasapgil, B. 1995. Determination of operating criteria for pre-acidification of dairy wastewater. In: Proceedings of 50th Purdue Industrial Waste Conference, pp. 1-16.

Kasapgil, B., Anderson, G.K. and Ince, O. 1994. An investigation into the pre-treatment of dairy wastewater prior to aerobic biological treatment. Water Sci. Technol., 29: 205.

Kissalita, W.S., Lo, K.V. and Pinder, K.L. 1989. Influence of dilution rate on the acidogenic phase products distribution during two-phase lactose anaerobiosis. Biotechnol. Bioeng., 34: 1235-1250.

Kissalita, W.S., Lo, K.V. and Pinder, K.L. 1989. Kinetics of whey-lactose acidogenesis. Biotechnol. Bioeng., 33: 623-630.

Kissalita, W.S., Lo, K.V. and Pinder, K.L. 1990. Influence of whey protein on continuous acidogenic degradation of lactose. Biotechnol. Bioeng., 36: 642-646.

Kolarski, R. and Nyhuis, G. 1995. The use of sequencing batch reactor technol-ogy for the treatment of high strength dairy processing waste. In: Proceedings of the 50th Purdue International Waste Conference, pp. 485-494.

Komatsu, T., Hanaki, K. and Matsuo, T. 1991. Prevention of lipid inhibition in anaerobic processes by introducing a two-phase system. Water Sci. Technol., 23: 1189-1200.

Koster, I. 1987. Abatement of long-chain fatty acid inhibition of methanogenic by calcium addition. Biol. Wastes, 25: 51-59.

Malaspina, F., Stante, L., Cellamare, C.M. and Tilche, A. 1995. Cheese whey and cheese factory wastewater treatment with a biological anaerobic-aerobic process. Water Sci. Technol., 32: 59-72.

McInerney, M.J. 1988. Anaerobic hydrolysis and fermentation of fats and proteins. In: Zehnder, A.J.B. (ed), Biology of Anaerobic Microorgan-isms. New York, Wiley, pp. 373-416.

Monroy, O.H., Vazquez, F.M., Derramadero, J.C. and Guyot, J.P. 1995. Anaerobic-aerobic treatment of cheese wastewater with national technology in Mexico: The case of 'El Sauz'. Water Sci. Technol., 32: 149-156.

Orhon, D., Gorgun, E., Germirli, F. and Artan, N. 1993. Biological treatability of dairy wastewaters. Water Res., 27: 625-633.

Ozturk, I., Eroglu, V., Ubay, G. and Demir, I. 1993. Hybrid upflow anaerobic sludge blanket reactor (HUASBR) treatment of dairy effluents. Water Sci. Technol., 28:77-85.

Pavlostathis, S.G. and Giraldo-Gomez, E. 1991. Kinetics of anaerobic treatment. Water Sci. Technol., 24: 35-59.

Perle, M., Kimchie, S. and Shelef, G. 1995. Some biochemical aspects of the anaero-bic degradation of dairy wastewater. Water Res, 29: 1549-1554.

Petruy, R. and Lettinga, G. 1991. Digestion of a milk-fat emulsion. Bioresour. Technol., 61: 141-149.

Ramasamy, E.V., Gajalakshmi, S., Sanjeevi, R., Jithesh, M.N. and Abbasi, S.A. 2004. Feasibility studies on the treatment of dairy wastewaters with up flow anaerobic sludge blanket reactors. Bioresour. Technol., 93: 209-212.

Rico Gutierrez, J.L., Garcia Encina, P.A. and Fdz-Polanco, F. 1991. Anaerobic treatment of cheese-production wastewater using a UASB reactor. Bioresour. Technol., 37: 271-276.

Rinzema, A., Alphenaar, A. and Lettinga, G. 1993. Anaerobic digestion of long-chain fatty acids in UASB and expanded granular sludge bed reactors. Process Biochem., 28: 527-537.

Sayed, S., Zanden, J., Wijiffels, R. and Lettinga, G. 1988. Anaerobic degradation of the various fractions of slaughterhouse wastewater. Biol. Wastes, 23: 117-142.

Strydom, J.P., Britz, T.J. and Mostert, J.F. 1997. Two-phase anaerobic digestion of three different effluents using a hybrid bioreactor. Water Salination, 23: 151-156.

Van den Berg, L. and Kennedy, K.J. 1992. Dairy waste treatment with anaerobic stationary fixed film reactors. In: Malina, J.F. and Pohland, F.G. (eds.) Design of Anaerobic Processes for the Treatment of Industrial and Municipal Wastes. Technomic Publishing Company, Pennsylvania, pp. 89-96.

Vidal, G., Carvalho, A., Mendez, R. and Lema, J.M. 2000. Influence of the content in fats and proteins on the anaerobic biodegradability of dairy wastewaters. Bioresour. Technol., 74: 231-239.

Wheatley, A. 1990. Anaerobic Digestion: A Waste Treatment Technology. Elsevier Applied Science, London and New York.

Yan, J.Q., Lo, K.V. and Liao, P.H. 1989. Anaerobic digestion of cheese whey using up-flow anaerobic sludge blanket reactor. Biol. Wastes, 27: 289-305.

Yan, J.Q., Lo, K.V. and Liao, P.H. 1990. Anaerobic digestion of cheese whey using up-flow anaerobic sludge blanket reactor. Sludge and substrate profiles. Biomass, 21: 257-271.

Yan, J.Q., Lo, K.V. and Pinder, K.L. 1993. Instability caused by high strength of cheese whey in a UASB reactor. Biotechnol. Bioeng., 41: 700-706.

Yu, H.Q. and Fang, H.H.H.P. 2001. Acidification of mid- and high-strength dairy wastewaters. Water Res., 35: 3697-3705.

Yu, H.Q. and Fang, H.H.H.P. 2001. Inhibition on acidogenesis of dairy wastewater by zinc and copper. Environ. Technol., 22: 1459-1465.

Yu, H.Q. and Fang, H.H.P. 2000. Thermophilic acidification of dairy wastewater. Appl. Microbiol. Biotechnol., 54: 439-444.

Yu, J. and Pinder, K.L. 1993. Intrinsic fermentation kinetics of lactose in acidogenic biofilms. Biotechnol. Bioeng., 41: 479-788.

Yu, Y., Hansen, C.L. and Hwang, S. 2002. Biokinetics in acidogenesis of highly suspended organic wastewater by adenosine 5-triphosphate analysis. Biotechnol. Bioeng., 78: 147-156.