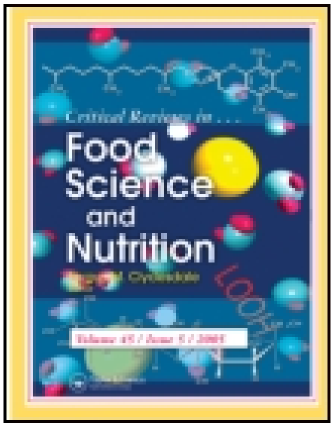

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Current Strategies for Dairy Waste Management: A Review

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Current Strategies for Dairy Waste Management: A Review

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Industrial waste management is nowadays one of the main issues for ensuring a sustainable environment. Dairy waste management in particular, is very crucial in view of the high organic matter and high nutrient levels contained in dairy effluents. Dairy waste can be effectively treated either with aerobic or anaerobic processes. The main advantages of the former consist of low yield, high kinetics, pathogen free product, and high temperature operation whereas the latter is a simple, low budget and conservative technology. Occasionally, pre-treatment strategies (i.e. wetlands) are required in order to improve the efficiency of treatment methodology. Wetlands are a promising technology applied in order to remove the greater part of nutrients and minerals contained in milk based products.

Keywords dairy industry waste, aerobic, anaerobic, wetlands, sustainability, bioremediation

INTRODUCTION

The production process of dairy products results in a significant amount of waste mainly in the form of chemically modified liquids. The latter are characterized by high organic load (e.g. fatty acids and lactose), considerable variations in pH (4.2–9.4) as well as increased content of suspended solids (0.4–2 g/l) (Kosseva et al., 2003). Moreover, since the water requirement of a dairy plant for washing and cleaning operations corresponds to 2–5 litres of water per litre of processed milk (Amritkar, 1995), dairy industries produce a large amount of wastewater per day. The dairy wastewater usually contains proteins, salt, fatty substances, lactose as well as residues of chemicals used during cleaning processes (Thassitou and Arvanitoyannis, 2001). The influence of those chemicals and their additives to the COD (Chemical Oxygen Demand) of the dairy wastewater is rather small, compared to the one caused by the presence of other components such as milk cream or whey (Wildbrett, 1988). However, detergents often contain sequestering agents and surfactants (Grasshoff, 1997) shown to strongly affect the river ecosystems due to their high toxicity to aquatic animals (IDF, 1993).

Furthermore, flow and characteristics of the wastewaters vary from one factory to the other, since a great variety of systems, technologies, operational methods but also final products are being used or produced (Rico et al., 1991). The application of the ISO 14000, resulted in compliance with the increasingly demanding standards of environmental management systems for industries with considerable challenges in a number of areas such as water availability, wastewater discharge, air emissions, chemical residues, solid waste disposal and food packaging materials (Boudouropoulos and Arvanitoyannis, 2000). Several studies concluded that discharging wastewater with high levels of nutrients such as phosphorus and nitrogen, led to eutrophication of receiving waters. Wastewaters from dairy industries often contain high nutrient levels (Brown and Pico, 1979).

Several regulatory agencies in many countries, like the United States, have placed restrictions to the nutrient discharge through wastewater effluents. For example, a phosphorus discharge limit of 1.0 mg/l was introduced for Wisconsin on January 1, 1997 [Wisc. Adm. Code NR 217.04, 1997 (Raskin et al., 1998)]. It was therefore crucial for the industries such as dairy manufacturers, to develop efficient and economically profitable ways of waste management, thus resulting in reduction of the levels of multiple severe contaminating factors (chemical and biological).

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Physical-chemical treatments aim at removing the organic load of dairy wastewaters up to a point. The success of those methods depends on how efficient will be the formation of precipitants of specific components of the dairy whey (such as proteins and fat) with chemicals compounds such as aluminum sulphate, ferric chloride, and ferrous sulphide (Karpati et al., 1995; Ruston, 1993). Since the reagent cost is high and the removal of soluble chemical oxygen demand (COD) is poor, biological methods are frequently used.

Some of the waste treatment methods developed in the past are discussed below. These include two thermophilic bioremediation strategies which take place in two steps; one anaerobic and one aerobic. Furthermore, one strategy for waste management based on anaerobic digestions with the use of upgraded CST (Continuously-Stirred Tank) reactors, construction of wetlands for an initial treatment of wastewaters from dairy farm operations, as well as the potential for Biological Nutrient Removal (BNR) of that type of wastewaters is discussed.

DAIRY WASTE TREATMENT METHODOLOGY

Thermophilic Bioremediation for Dairy Waste Management

Various methods based on mesophilic aerobic and anaerobic digestions of whey and whey derivatives have been reported for dairy waste treatment (Cristiani-Urbina, Netzahuatl-Munoz, et al., 2000). However, since many countries [like India which possessed an annual milk production of 50 million tones at 1990 (Ramasamy and Abbasi, 2000)] produce large quantities of dairy products which inevitably results in large volumes of excess whey, a considerable disposal problem raises. In addition, more stringent regulations regarding direct spraying on to land, hygiene issues to sludge disposal from mesophilic biotreatment, and reduction in the use of landfilling were voted.

Thermophilic aerobic bioremediation treatment is a technology for treating high-strength organic waste streams (Rozich and Bordacs, 2002) endowed with characteristics which may hopefully provide answers to the above mentioned problems, since it combines the advantages of low biomass yields and rapid kinetics with those of high temperature operation and stable process control of aerobic systems [Table 1 (Kosseva et al., 2003)].

Kosseva and colleagues (2003) have compared two strategies of thermophilic waste treatment. The first consists of an anaerobic, mesophilic first stage, followed by a aerobic, mesophilic second stage. The second includes an anaerobic, mesophilic first stage, followed by an aerobic, thermophilic second stage (Kosseva et al., 2003). The following scheme of reactions to describe the formation of biomass out of lactose found in whey was proposed:

Table 1 Main advantages of thermophilic biological methods

Low mass yield
Rapid kinetics
High temperature operation
Stable process control of aerobic systems
Production of pathogen-free products
Energy generation

The homofermentative lactic acid bacteria (LAB) produce lactase, which hydrolyses the lactose found in whey to glucose and galactose:

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6 \quad (1)$$

Lactic acid is produced via the Emden–Meyerhof–Parnas glycolitic pathway, via pyruvic acid (*showing only the main reagents and products*):

$$2C_6H_{12}O_6 \rightarrow 4C_3H_4O_3 + 8H^+ \rightarrow 4C_3H_6O_3 + 4ATP \quad (2)$$

The thermo-tolerant yeast directly utilizes lactose to produce ethanol and carbon dioxide:

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 4C_2H_5OH + 4CO_2 \quad (3)$$

Biomass formation might be described by the following simplified reaction scheme:

$$aCH_xO_y + bH_lO_mN_n \rightarrow CH_\alpha O_\beta N_\chi + cH_2O + dCO_2 \quad (4)$$

where CH_xO_y is a carbon source, $H_lO_mN_n$ is a nitrogen source, and $CH_\alpha O_\beta N_\chi$ is biomass formed.

A Comparison of the Effectiveness between the Two Strategies

According to Kosseva et al. (2001), DO was maintained at or above 80% of saturation during aerobic processing in both strategies. Regarding the first strategy, a simultaneous degradation of carbon sources occurred which resulted mainly in carbon dioxide and biomass. Furthermore, the release of carbon dioxide was closely related with consumption of lactate. The respiratory quotient remained near a value of 1 during consumption of lactate while the total decrease of soluble chemical oxygen demand (COD) of whey during the anaerobic and aerobic stages proposed scheme was 68%. Finally, the soluble protein decreased by 59%. As regards the second strategy, DO was maintained above 65% of saturation. During the consumption of lactate, the respiratory quotient remained near a value of one, as proved by the similarity between the curves of the oxygen depletion and those of carbon dioxide enhancement.

The average lactate biodegradation rate over the digestion period varied between the two processes. In particular, during the mesophilic process at 45°C the average velocity was 0.5 g/h. On the contrary, during the thermophilic process at 65°C the measurements for the same characteristic gave an average velocity of twice as high [0.96 g/h]. Considering only the thermophilic treatment, the average decrease of COD was 62.5% while for soluble protein was approximately 47.5% (Kosseva et al., 2003). Following the mesophilic-thermophilic strategy, approximately

Table 2 A comparison of the two bioremediation strategies for the management of dairy waste (Adapted from Kosseva et al., 2003)

Mesophilic anaerobic first stage and mesophilic aerobic second stage	Mesophilic anaerobic first stage and thermophilic aerobic second stage
DO maintained above 80% of saturation during the aerobic stage	DO maintained above 65% of saturation during the aerobic stage
The respiratory quotient remained near a value of 1 during consumption of lactate	The respiratory quotient remained near a value of 1 during consumption of lactate
The average velocity of lactate biodegradation was approximately 0.5 g/(1 h)	The average velocity of lactate biodegradation was approximately 0.96 g/(1 h)
The total decrease of soluble COD of whey was 68%	The total decrease of soluble COD of whey was 62.5%
The total decrease of soluble protein was 59%	The total decrease of soluble protein was 47.5%

100% reduction of soluble COD and lactose was recorded accompanied with a 90% decrease in soluble protein in batch cultures. A comparison between the two strategies is summarized in Table 2.

It was also proposed that the ethanol produced at step 3, produces acetic acid via bio-oxidation. Further, bio-oxidation of acetic, lactic, and citric acid finally produces carbon dioxide and water.

Anaerobic Management of Dairy Waste with the use of Upgraded CST Reactors

Anaerobic digestion is one of the major steps involved in the treatment of dairy industry wastewaters through processing CSTRs (Continuously-Stirred Tank Reactors) (Ramasamy and Abbasi, 2000). Many studies were conducted in order to improve the performance of the particular technology, one of which includes the incorporation of a biofilm support system (BSS) within the reactor (Ramasamy and Abbasi, 2000). The properties of the wastewaters (high organic content and presence of nutrients) ensure the growth of micro-organisms and therefore the facile biological degradation, biodegradation treatments of wastewaters from dairy industries can be easily developed and adopted.

Surveys of the current effluent-treatment systems revealed that the aerobic activated sludge treatment is the most highly energy intensive and widely used. Several conventional aerobic treatments have been used extensively in the dairy industry which include aerated lagoons, activated sludge processes (Stephenson, 1989; Scack and Shandhu, 1989), trickling filters (Walsh et al., 1994) and rotating biological contactors (Radick, 1992). Apart from the high energy consumption of the particular technologies for aeration, it can not always ensure a stable performance due to a variety of factors such as overloading, seasonal flow variations, and bulking sludge (Ramasamy and Abbasi, 2000; Timmermans et al., 1984).

On the contrary, the characteristics of the anaerobic technology for waste treatment not only ensure a low-budget operation, no need for aeration equipment, lower excess of sludge, relatively low land demand (Colleran, 1991; Perle et al., 1995) but also are accompanied with the prospect of energy production through the utilization of the main product of the process, methane (Ramasamy and Abbasi, 2000).

The Principles of the CST Methodology

Among the various technologies used for dairy waste anaerobic treatment, one of the most common and easiest is the CSTRs (Figure 1). According to the method, the digester contents are mixed either continuously or periodically. The key for a good biodegradation is the maximization of the contact surface between wastewater components and the anaerobic microbes. The CSTR assay showed good mixing properties which in turn ensure a high biodegradation. However, efforts were made focusing on performance improvement of this particular technology, mainly by limiting the presence of active microbial biomass from the reactor washout. Ramasamy and Abbasi (2000) tried to retain a portion of the active biomass within the reactor with the use of BSS (Biofilm Support System). The concept of this particular technology was that the BSS application would provide the support media for the active microbes to

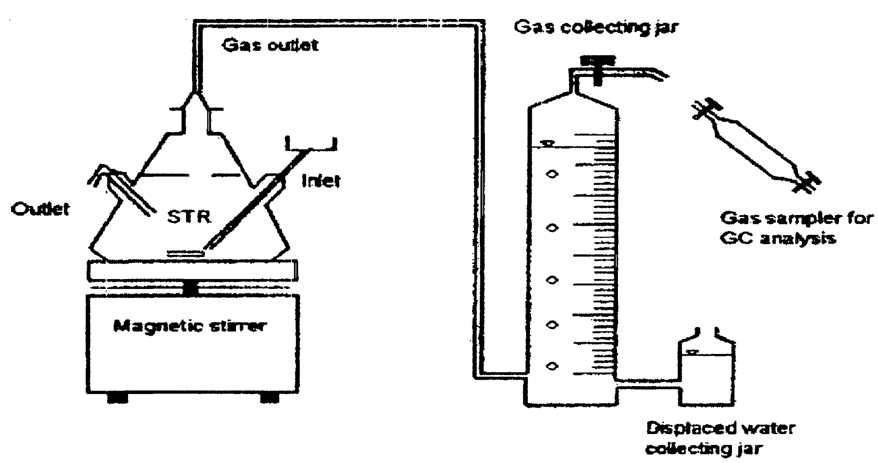

Figure 1 A typical stirred tank reactor (STR) (Ramasamy and Abbasi, 2000).

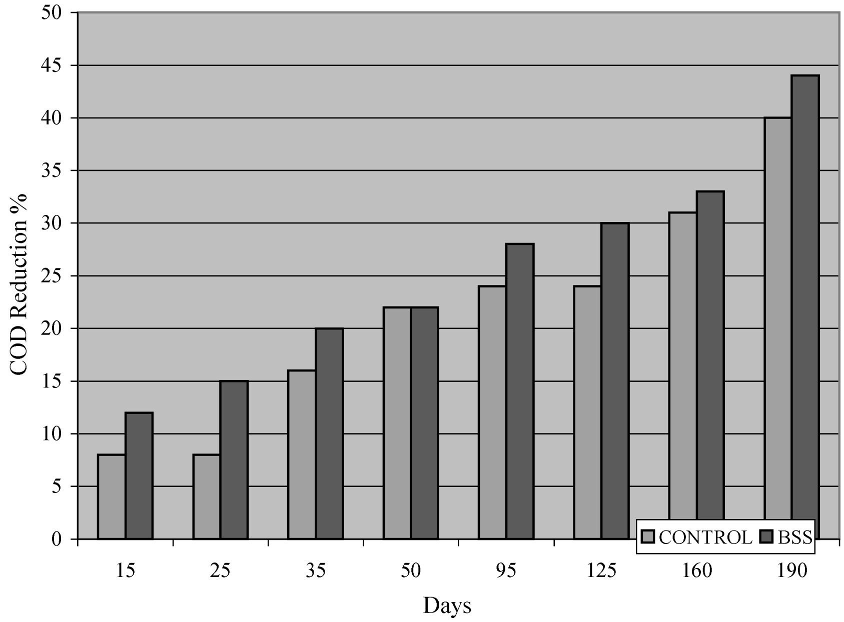

Figure 2a Comparison of start up perfomance between conventional and BSS-ST reactors regarding COD reduction (Adapted from Ramasamy and Abbasi, 2000).

attach and growth, thus making the biodegradation process more effective.

Ramasamy and Abbasi (2000) used as initial feed for the reactor a mixed liquor, which was then replaced with dairy waste exclusive use. As soon as the feeding of the reactor began, the biogas production also started in both normal (served as control in their experiments) and BSS reactor. The COD reduction of the effluent was found to be low (Figure 2a). But as soon as they used dairy waste as the only feed composition substrate (50 days), the biogas yield increased (Figure 2b).

A greater COD reduction was also reported in the BSS reactors than in the conventional ones. VS destruction was found to be of an average of 60% in the BSS and only 40% in the control reactor, when the HRT (Hydraulic Retention Time) was reduced to 10 days. The biogas released by both reactors was of a rate of 56 to 58%.

Vidal and colleagues (2000) introduced a different approach to the specific technology. On their survey they have proved that dairy wastewaters with differences in fat and protein content and quality, can have a serious impact on the performance and efficiency of the anaerobic reactors (Vidal et al., 2000). As mentioned above, the variety of dairy products is wide and that leads to the necessity to have a reliable anaerobic technology to treat those wastewaters regardless their protein and fat contents.

In their experiments, Vidal et al. (2000) used two types of wastewater compositions, the W-type obtained by dissolving full cream milk powder and the S-type obtained from shimmed milk powder (Figures 3a and b). A direct relation between the

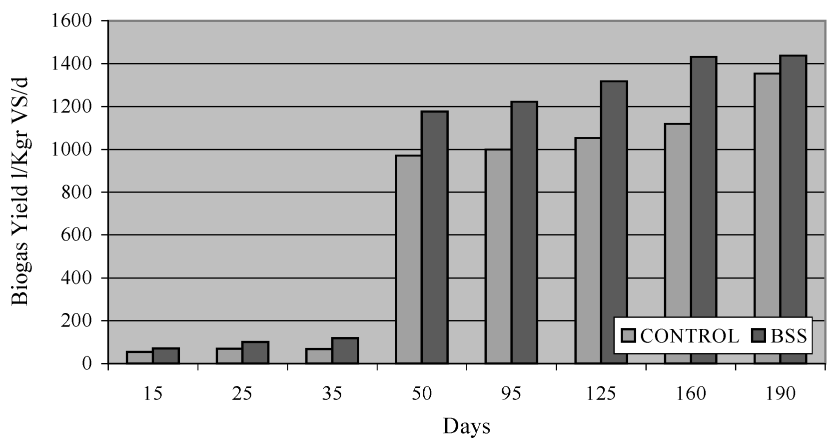

Figure 2b Comparison of start up perfomance between conventional and BSS-ST reactors regarding biogas production. (Adapted from Ramasamy, Abbasi, 2000)

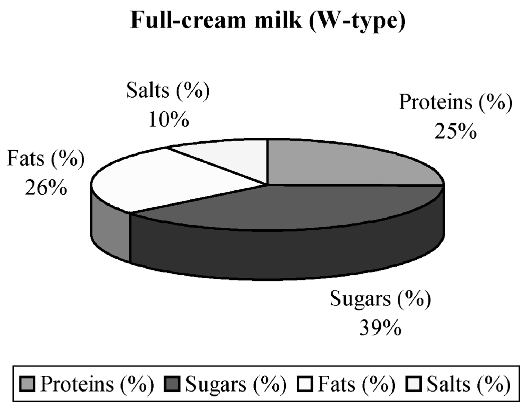

Figure 3a Composition of full-cream per 100 g of milk powder (Adapted from Vidal et al., 2000).

initial amount of proteins and the final ammonia concentration and pH value of the assay was established. Sugars degraded in W-samples (with residual sugars) whereas almost all of the sugars were degraded in the S-samples (Table 3, Figures 4a and b). They have also reported that different anaerobic degradation kinetics was observed for the two types of wastewaters. Furthermore, at lower concentrations (1–5 gCOD/l) the biodegradability and the methanization were greater in the case of the W wastewaters. At higher concentrations (5–20 gCOD/l) the biodegradability of W wastewaters ranged between 98% and 99% while the one of the S wastewaters diminished from 97.5% to 86%.

Construction of Wetlands in Order to Treat Wastewaters from Dairy Operations

In the previous sections a presentation was made of the currently employed technologies toward treating the wastewaters from dairy industries using mostly biological digestions under both aerobic and anaerobic conditions. As already mentioned, dairy wastewaters carry a high organic load and have a considerable content in nutrients such as P and N. P and N are the two main factors which contribute to the eutrophication of receiving lakes and/or rivers. Wastewater production of a heavy organic load and nutrients, both leading to eutrophication, also occurs in the dairy farms. Since the typical operation of a dairy farm, includes a flush after each milking, some portion of the producing milk enters the waste streams through rinsing transfer pipes and storage tanks (Cronk, 1996).

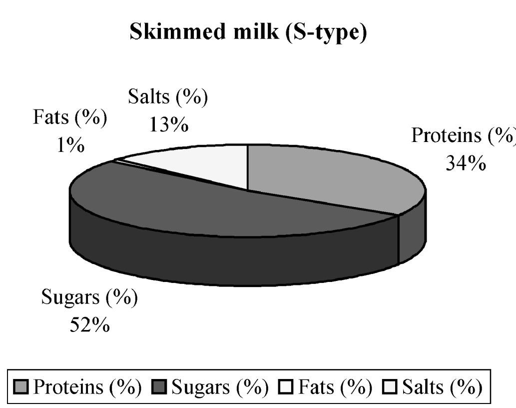

Figure 3b Composition of full-cream per 100 g of milk powder (Adapted from Vidal et al., 2000).

Milk's five-day biological oxygen demand (BOD) is 100.000 mg per litre, which is high due to the existence of fat, sugars, and proteins. Other contaminants that might end up to surface or underground receiving waters of the dairy farm surrounding area, are detergents which are usually alkaline and may contain phosphates as well as water softeners containing sodium and chloride. From 20 to 40 l of fresh water per day and the cow can be used if flushing of waters is not practiced and up to 600 l of fresh water per day and the cows are used if cow and manure washing is part of the procedure (NRCS, 1992).

Principles of the Wetlands Methodology

It is therefore essential for provisions to be made on how dairy farm wastewaters can undergo a primary solids separation. The basic scheme of this procedure includes the construction of a settling basin in which basic separation of solids occurs due to precipitation and then the wastewaters can flow into a lagoon and/or be land spread.

Constructed wetlands could replace or be downstream from the lagoon and they could replace land spreading, especially now that more strict regulations about it are applied (Figure 5). Septic tanks can also be used for treatment of dairy waste. However, possible formation of a bacterial slime can clog soil pores in the drain system (Midwest Plan Service, 1987). If however, a septic tank is in place, a constructed wetland could also receive and treat the liquid portion of waste.

Characteristics of Wetlands Wastewater Treatment

Several natural and constructed wetlands have been tested for their ability to retain or transform nutrient inputs from municipal wastewater (Odum et al., 1977; Dierberg and Brezonik, 1983; Kadlec, 1987; Knight et al., 1987; Brodrick et al., 1988; Hammer, 1989). These have proven effective by decreasing nitrogen, phosphorus, suspended solids, and BOD of dairy wastewaters (Cronk, 1996).

A dairy farm wetland is very appealing as a waste management method because it is low-cost, with relatively low requirements for technology know-how and with careful planning requires little human-controlled energy input after construction (Hammer, 1992). However, BOD concentrations in livestock wastewater are at least an order of magnitude higher than those in domestic wastewaters. Therefore, although wetlands for secondary and tertiary sewage treatment were proven successful, new designs to be adapted for the high BOD and nutrient characteristics of animal wastewaters, are necessary.

Thus, wetlands for animal wastewater treatment should always be coupled with additional waste management strategies.

Table 3 Initial and final concentration of the major components of the W- and S-wastewaters after the anaerobic digestion. (Adapted from Vidal et al., 2000)

	Initial Conditions (mg/l)				Final Conditions (mg/l)			
	W-COD	W-Fat	W-Protein	W-Sugar	W-COD	W-Protein	W-Fat	W-Total ammonia
W-type	689	121	120	175	78	32	14	0
	1377	239	240	350	51	53	8	0
	3444	598	600	875	91	42	18	0
	5548	964	965	1410	100	48	28	120
	11101	1928	1932	2822	130	135	56	159
	16639	2890	2895	4229	175	261	85	384
Mean	6466	1123	1125	1644	104	95	35	111
	S-COD	S-Fat	S-Protein	S-Sugar	S-COD	S-Protein	S-Fat	S-Total ammonia
S-type	396	4	135	207	100	43	16	0
	791	8	24	414	73	4	8	0
	1978	20	676	1035	176	61	0	0
	6549	66	2240	3427	132	112	0	102
	13114	131	4485	6863	400	0	0	488
	19668	197	6727	10293	3011	0	0	1196
Mean	7083	71	2381	3707	649	37	4	298

Several pretreatment strategies are in use and their effectiveness is of great importance to the constructed wetlands performance. The accumulation of solids shortens the effective life of a constructed wetland, making solid removal a necessary pretreatment step. Upstream settling basins, lagoons, or septic tanks can remove solids and ideally release only liquid effluent for treatment within the wetlands (Cronk, 1996).

Many of the most elaborate pre- and post-treatment systems are at research and demonstration sites. It may be more difficult to plan and operate these components on a private farm since daily operation may be labor intensive and expensive. Nonetheless, upstream removal of BOD and TSS is essential to any animal wastewater treatment wetland because the concentrations are typically too high to be treated in a wetland. Without pretreatment, a constructed wetland is ineffective (Reaves et al., 1994b).

Plants have also a beneficial action on the waste management with wetland, as a substrate and a carbon source for microbes. Wetland species oxygenate the substrate immediately to their roots and therefore increase the aerobic portion of an otherwise anaerobic zone (Brix, 1993). Plants are also in need of minerals for their development, which can be obtained by absorption of wastewater components like N and P. Plant nutrient uptake is usually not the major pathway of nutrient removal such as N and P from the wastewaters but nevertheless it has been credited with 16–75% of the total N removal and 12–73% of total P removal (Reddy and DeBusk, 1987).

There are some characteristics that plant species should have in order to be qualified for establishment near a wetland. Those plants should have high productivity in order to ensure major nutrient uptake, they should be able to produce a rich and near to surface rhizome and to be able to colonize. In order to ensure a more stable performance, perennial species are preferable (Hammer, 1993) and of course they should be easily and

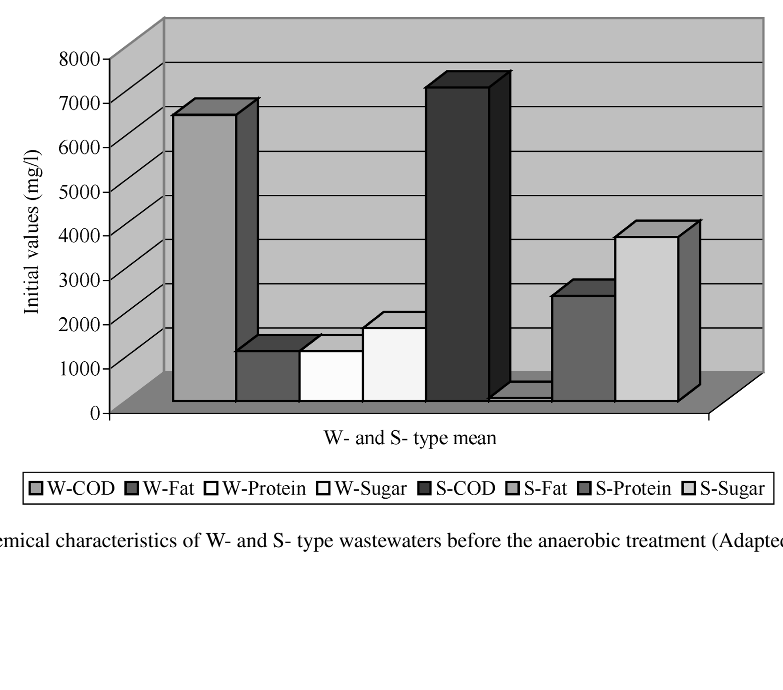

Figure 4a Initial chemical characteristics of W- and S- type wastewaters before the anaerobic treatment (Adapted from Vidal et al., 2000)

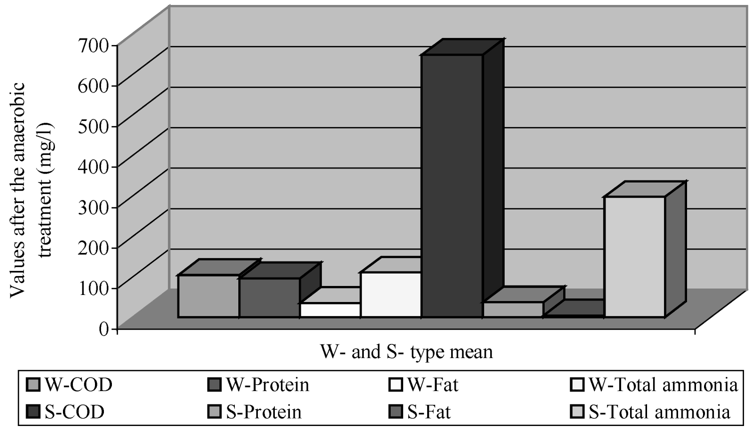

Figure 4b Final chemical characteristics of W- and S-type wastewaters after the anaerobic treatment (Adapted from Vidal et al., 2000).

inexpensively obtained. Regarding some specific characteristics which will ensure the survival of those species under the wetland conditions, these plants must tolerate high concentrations of nutrients and, in particular, ammonia unless reliable pretreatment methods are used to control this pollutant (Cronk, 1996).

Wetlands can not be constructed in every type of soil. In any other case, that could only enhance the problem of underground waters pollution. The site of an animal wastewater treatment wetland must be predetermined by the topography of the farm, existing structures and land availability. Hydraulic conductivity should be measured and if it is greater than considered desirable [under 10^{-6} cm s^{-1} (Hammer, 1994) a clay or plastic liner perhaps will be able to retain standing water and prevent contamination. Calculation of the investment required for wetlands construction includes the following costs: an engineering plan, preconstruction site preparation, construction (including labor, equipment materials and supervision), long-term management, pest controls, as well as contingency (Tomljanovich and Perez, 1989).

Further factors which can contribute to the increase of the cost is the type of the wetland, the singularity of the location, the treatment objectives, as well as the special characteristics of some substrates, the addition of a clay or plastic liner, the cost of protective structures and the required maintenance cost (Newling, 1982). Maintenance includes active management of the solid portion of the waste. In order for the wetland to treat effectively the waste, the amount of solids entering it must be minimized. Solids management is an ongoing problem and the farmers are advised to pre-consider it (Healy and McLoud, 1994; Reaves et al., 1994b).

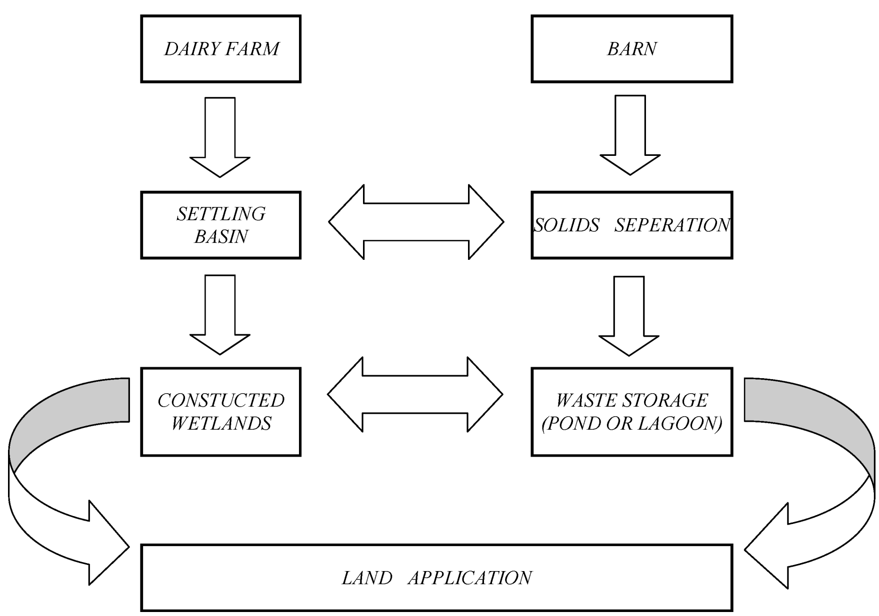

Figure 5 Proposed scheme for the handling operations for the dairy farm wastewaters (adapted from Cronk, 1996, and NRCSB, 1992).

Table 4 The advantages and disadvantages of both aerobic and anaerobic technologies for dairy waste management

Aerobic technologies	Anaerobic technologies
Advantages	
Low mass yield	Simple technology
Rapid kinetics	Low budget requirements
High temperature operation	Energy conservative
Stable process control of aerobic systems	Potential of energy generation from utilization of the producing methane
Production of pathogen-free products	
Energy generation	
Disadvantages	
Energy intensive	Washout of active microbial biomass
Uncertainty in achieving a stabilized performance	Low efficiency (with potentials of improvement)

Potential for Biological Nutrient Removal Treatment of Dairy Wastewaters

Dairy Wastewaters Production

As mentioned above, wastewaters from dairy industries, contain a heavy organic load due to the existence of proteins (such as casein), fats, and sugars. This type of wastewaters also contains nutrients such as nitrate and phosphorus which can lead to eutrophication effects to the receiving lakes and rivers, if provision regarding the removal of the above, does not take place.

Biological Nutrient Removal (BNR) is a technology including pre-treatment practices in order to alter the properties of the wastewater (municipal either industrial) in a way which will eventually allow the removal of specific nutrients (such as N and P) with the use of microrganisms. According to Reardon (1994), enhanced biological phosphorus removal (EBPR) can be more cost effective than the usual chemical precipitation methodologies. EBPR combined to nitrification or denitrification of dairy wastewaters can provide an alternative for the reduction of the dairy wastewaters high nutrient content. However, since there is a variety of dairy industries, each of those producing different final dairy products, one can easily conclude that their corresponding wastewater properties will significantly differ. In fact, that is the case and due to which, high variations in flow and chemical characteristics make the BNR of this type of wastewaters not a straightforward process (Danalewich et al., 1998).

Harper and colleagues in the late 60s (1971) carried out a survey over the dairy waste characteristics. According to their results, although dairy wastewaters carry a heavy organic load, dairy industry had limited knowledge of that fact. In addition, the concentrations of many wastewaters components (such as nutrients) were not determined. It was also reported that the existing on site treatment systems had low efficiencies (Harper et al., 1971). A similar survey was carried out in order to determine the effectiveness status of the current dairy wastewater treatment practices and also to estimate the potential for BNR (Danalewich et al., 1998). In that study 14 dairy industries, 12 of which producing one or more types of cheese and processed dairy whey as a secondary product were included. In other studies waste generation was shown to be characterized by high daily fluctuations in association with washing procedures at the end of production cycles (Goronszy, 1989; Eroglu et al., 1991)]. Furthermore, high seasonal variations frequently occur and are correlated with the volume of milk received for processing, which is typically high during summer and low during winter months (Eroglu et al., 1991; Kolarsji and Nyhuis, 1995).

Harper and colleagues (1971) have concluded that management planning and efficiency of management supervision were the controlling factors in the amount of wastewater produced. Danalewich and colleagues (1998) reported significant reduction in the volume of wastewaters produced per amount of milk processed, compared to Harper's results. It was concluded that the increase in the industries size, the automation in product processing and the introduction of cleaning-in-place (CIP) systems over the last few decades resulted in considerable reduction. However, they also mentioned that management strategies are still the major factor determining the waste generation (Danalewich et al., 1998).

In an attempt to evaluate the contribution of specific industrial activities to wastewater generation, it was shown that cleaning transport lines and equipment between production cycles as well as cleaning tank trucks and washing milk silos, appeared to be the most important factors in waste generation (Table 5), followed by equipment malfunctions and/or operational errors (Eroglu et al., 1991).

Table 5 Contribution of industrial activities in wastewater generation. (Adapted from Danalewich et al.,1998)

Specific production activities	% Percentage of industries which consider the specific activity as:	
	Major contributor	Minor contributor
Cleaning of transport lines and equipment between production cycles	28.6	71.4
Cleaning of tank trucks	21.4	64.3
Washing of milk silos	21.4	64.3
Milk and milk product spills during processing	0	85.7
Milk spills during receiving	0	85.7
Milk and milk products discharge during production start up and change over	0	85.7
Leakage from pipes, pumps and tanks	0	64.3
Overflow from tanks	0	64.3
Loss during packing operations	0	64.3
Discharge of cooling water	0	28.6
Discharge of spoiled milk and milk products	0	21.4
Lubrication of casers, stackers, conveyors and other equipment	7.1	7.1
Cleaning of whey evaporators	7.1	7.1
Sterilization of equipment	0	7.1
Vegetable oil leaks	0	7.1

Table 6 Preatreatment and final treatment stategies for dairy wastewaters of ranging temperature and pH value (Adapted from Danalewich et al., 1998)

Dairy wastewater			
pH	Temperature (Celsius degrees)	Pre-treatment strategy	Final treatment
(3–13)	(32–43)	Treatment in equalization basin, DAF, trickling filters, oxidation ditch, post treatment in series of two lagoons before discharge into river, chemical additions include polymers for dewatering and sulfuric acid for pH adjustment	Aerobic digester, thickening tank, filter press, composting, land application
(7.5–8.1)	(2.8–21)	Pretreatment in equalization basin and conventional activated sludge system	Belt filter press dewatering and land application
(1–14)	(14–32)	Pretreament in equalization basin and completely-mixed activated sludge system	Land application
(4.8–11.3)	(22–38)	Pretreatment in grit chamber, extended aeration activated sludge system with addition of ferric chloride for phosphate precipitation and addition of polymers in clarifiers	Aerobic digestion, gravity thickening, land application

Influence of Chemical Usage on Wastewaters Properties regarding BNR

Harper et al. (1971) and Danalewich et al. (1998) reported on the chemical usage practises in the dairy industry since 1960 (Table 7). They have also made an interesting comparison between the current cleaning practices and the ones used during 1960 (Harper et al., 1971). They have concluded that the cleaning practices used in dairy industries have been altered significantly during the last decades. The use of nitric acid for high temperature cleaning of equipment was not utilized during 1960 while today it has replaced the various organic, sulphuric, and hydrochloric acids which were the most frequently used.

Nowadays, the swift from the use of phosphoric acid to phosphoric/nitric blends or nitric acid was accompanied by waste minimization practices such as reclamation of cleaning acids and caustic soda. Those changes probably are related to compliance of the dairy industries with stricter environmental regulations. The reduced use of organic acids corresponds to the implementation of the Clean Water Act (1972) whereas the switch from phosphoric to nitric acids is based on the implementation of regulations for an overall reduction in phosphorus limits. However, Brown and Pico (1979) mentioned that non-phosphate cleaners are not as effective as phosphate and that can lead to increase in the cleaning cost.

The use of caustic soda and various acids can have a severe effect on wastewater pH values, thus influencing the microbial activities during BNR (Table 6). The large variations in wastewater temperatures can also influence the effectiveness of BNR. This is due to the fact that the treatment practises employed, vary greatly among the industries.

Chemical Characteristics of Dairy Wastewaters suited for BNR

BNR is based on the wastewaters microbial treatment. Since living micro-organisms participate in a direct way in the process, the effectiveness of the method is assessed based on the achievement of an environment that will benefit their survival. Thus the wastewaters which are to be treated with BNR, must have certain chemical characteristics. If not, then pre-treatment methodologies are required.

The wastewater industries participated in Danalewich and colleagues (1998) survey, are described by a wide range of chemical characteristics mostly because they produce a variety of different products, as mentioned before (Figure 6). First of all, the mean values of total BOD_5 and COD confirmed that dairy wastewaters have high organic matter strength. Furthermore, the BOD_5/COD ratio in all cases was above 0.5 with a mean of 0.63 ± 0.16. Harper and his colleagues (1971) reached the conclusion that ratios below 0.6 can suggest a less efficient

Table 7 Chemical usage practises in the dairy industry since1960 (Harper et al., 1971; Danalewich et al., 1998)

Chemical factor	Usage description	Major effect on wastewater properties
Na_2CO_3	Component in alkaline cleaners	Effect on biological treatment efficiency due to the increase of pH values
NaOH		
Polyphosphates	Emulsification, dispersion and protein peptizing	
Sulphated alcohols	Wetting agent	Major contributor to the increase of BOD_5
Alkyl aryl sulphonates		
Quaternary ammonium surfactants		
Acetic acid, Propionic acid, Lactic acid, Citric acid, Tartaric acid	Organic acid cleaners utilized to clean high-temperature equipment	Effect on biological treatment efficiency due to the decrease in pH values, erosion of metallic parts of equipment
Phosphoric acid, Nitric acid, Sulphuric acid	Inorganic acid cleaners utilized to clean high-temperature equipment	Effect on biological treatment efficiency due to the decrease in pH values, erosion of metallic parts of equipment
Sodium hypochlorite, Iodine compounds, Quaternary ammonium compounds	Sanitizer	Impact on biological wastewater treatment efficiency

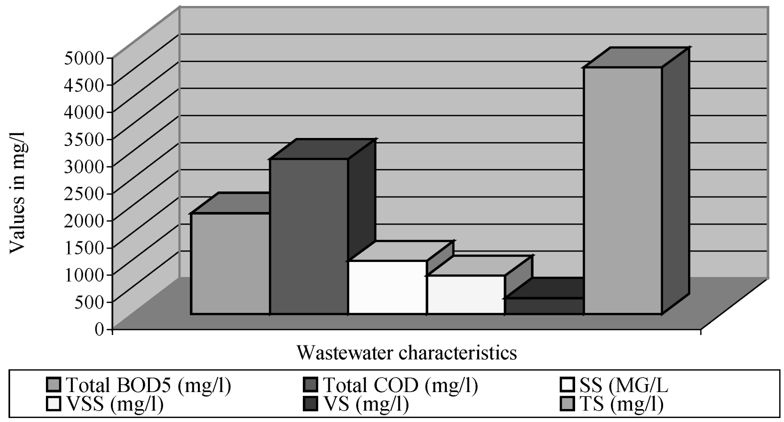

Figure 6 Chemical characteristics of dairy wastewaters (Adapted from Danalewich et al., 1998).

biological oxidation of milk waste compared to pure milk. When ratios are below 0.4, Harper et al. (1971) suggest that this is due to waste toxicity. Since low ratios coincided with major periods of equipment cleaning, toxicity can probably be related to cleaning operations. Danalewich et al. (1998) concluded that most of the dairy wastewaters are easily biodegradable.

As for the acidity of the wastewater samples, all had pH values above 6.0 and many above 7.0. This was attributed to the use of alkaline cleaners and sanitizers. Wastewater pH is a major factor affecting the biodegradation properties of the wastewaters because most microorganisms exhibit optimal growth in a pH range between 6.0 and 8.0 while values above 9.5 or below 4.0 cannot be tolerated (Danalewich et al., 1998). Furthermore, according to Tchobanoglous and Burton 1991), low pH levels are often connected with erosion of metallic parts of equipment. In that case, pre-treatment by using equalization basins can be installed upstream of biological treatment systems to stabilize wastewater pH (Danalewich et al., 1998).

Last but not least an important parameter is the organic matter to nitrogen ratio, expressed as the COD : TKN, BOD_5: TKN or BOD_5: NH_3-N ratio. These ratios are important to evaluate the potential for successful nitrogen removal since sufficient amounts of organic matter must be present, thus reducing equivalents for denitrification. Furthermore, poor phosphorus removal was attributed to the presence of nitrates in the anaerobic zone of activated EBPR sludge system. A number of studies suggest that EBPR inhibition in the presence of nitrate is due to competition by denitrifying bacteria (Iwema and Meunier, 1985; Yamamoto et al., 1990; Takeuchi, 1991; Carucci et al., 1994; Kuba et al., 1994). According to Grady and Daigger (1999), COD : TKN, BOD_5: TKN, and BOD_5: NH_3-N ratios greater than 9.5, and 8 should result in excellent nitrogen removal.

CONCLUSIONS

The thermophilic bioremediation technology appears to combine the advantages of low mass yields and rapid kinetics associated with high temperature operation and stable process control of aerobic systems. It also has the potential of both producing pathogen-free products and the generation of energy out of the process. Furthermore, the average velocity of the thermophilic bioremediation was almost twice as high as that under mesophilic conditions and compared to the fact that COD and soluble protein levels were reduced during the thermophilic process compared to the mesophilic one, calls for further investigation of the opportunities of this particular promising technology.

The aerobic technologies adapted by many dairy industries for processing of their wastewaters, are usually, highly energy intensive and may lead to uncertainty regarding a stabilized performance, due to factors such as overloading and bulking sludge. On the contrary, anaerobic technologies are simpler, require a lower budget to operate and have the potential of producing energy out of the utilization of the main process product, biogas with a high content in methane (Table 4).

As mentioned above, the different content of fat and proteins in the dairy wastewaters from industries with various products, can seriously relent the efficiency and performance of the anaerobic degradability. Vidal and his colleagues (2000) concluded that the anaerobic biodegradation of fat-rich wastewaters is slower than that of fat poor wastewaters, due to the slower rate of fat hydrolysis step. Furthermore, ammonia production seems to be significant in wastewaters with a high content in carbohydrates when the COD is high.

Although CST reactors stand for the simplest and most common anaerobic technology ensuring high biodegradation, the efficiency of the system is considerably reduced due to the washout of active microbial biomass from the reactor. Moreover, there are several ways to improve that performance (like using BSS) and to upgrade the conventional anaerobic technology in a way that will prove to be more competitive compared to the aerobic technology.

Wetlands are a promising solution towards reducing or pretreating a major portion of the pollutants such as minerals and nutrients like N and P, abundant in the dairy wastewaters. The effectiveness of wetlands can be ensured with careful design prior to construction and by taking into account factors such as the topography of the location and the characteristics of the wastewaters as well as pre-establishment of provisions for proper maintenance.

Nevertheless, the construction of a wetland is not always the ideal solution for waste treatment in every farm. Since there is no standard design that can be applied everywhere, a wetland may have to be altered after construction. A period of time is also necessary to elapse before the effective removal of the pollutants from a wetland takes place because plant and microbial communities must first get established before removal rates reach acceptable levels.

Recent surveys showed that coefficients in the dairy industry are 2 to 3 times lower than those in the 1960s. This reduction is attributed to increased plant size, automation in product processing, introduction of clean-in-place systems, and waste minimization practices such as recovery of chemicals and reuse of rinse waters.

These findings suggest that management strategies still stand for the determining factor in waste generation. Therefore, EBPR, in combination with nitrification and de-nitrification, will likely be the successful strategies toward removal of nutrients from dairy wastewaters.

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