13

Dairy Waste Management: Treatment Methods and Potential Uses of Treated Waste

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Introduction

The dairy industry has grown in most countries of the world because the demand for milk and milk products has steadily risen (Table 13.1). The production of milk per head of cattle has also grown as a result of advancements in veterinary science (Poompavai, 2002). However, total milk consumption (as fluid milk and processed products) per person varies widely from highs in Europe and North America to lows in Asia. Even within regions such as Europe, the custom of milk consumption has varied greatly. Consider for example the high consumption of fluid milk in countries like Ireland and Sweden compared to France and Italy where cheeses have tended to dominate milk consumption (http://www.foodsci.uoguelph.ca/dairyedu/intro.html).

The dairy industry is one of the largest sources of industrial effluents in Europe. A typical European dairy generates approximately 500 m^3 of waste effluent daily (Wheatley, 1990). The dairy wastewater usually contains proteins, salt, fatty substances, lactose as well as residues of chemicals used during cleaning processes (Thassitou and Arvanitoyannis, 2001). Since the dairy industry produces different products, such as milk, butter, cheese, yogurt, condensed milk, dried milk (milk powder), ice-cream, various types of desserts and cheese (Figure 13.1), the characteristics

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Table 13.1 Milk and milk products consumption per capita in various countries in the world

Country	Fluid milk (l)	Cheeses (kg)	Butter (kg)
Romania	163	1.1	0.5
Australia	92.8	11.9	2.7
USA	89.1	14.3	2.0
Russia	87.5	3.5	3.0
New Zealand	87.3	7.0	6.5
Canada	85.6	12.0	3.5
European Union (25 countries)	72.2	12.8	4.6
Ukraine	69.6	2.5	3.0
Brazil	65.9	2.6	0.4
Argentina	53.2	7.9	–
Mexico	40.1	2.0	1.1
Japan	37.8	2.0	0.7
India	32.3	–	2.5

Data 2004, adapted from http://www.foodsci.uoguelph.ca/dairyedu/intro.html

of these effluents also vary greatly, depending on the type of system and the methods of operation used (Vidal *et al.*, 2000). However, current awareness of environmental pollution from animal production has triggered research on the interface between animal production and the environment, to assess the ecological sustainability of various animal production systems in an integrated manner (Cederberg and Mattsson, 2000; Cederberg and Dalerius, 2000, 2001; Van Dijk, 2001; Haas *et al.*, 2001; de Boer, 2003; Basset-Mens and Van der Werf, 2005).

Among nations, India is one of the largest and is projected to become the largest producer of milk and dairy products in the world. With annual milk production grossing 85 million tonnes in the year 2002 and growing at the rate of 2.8% per annum (DAH&D, 2003), India is also by far the largest producer of dairy-based wastewaters.

During the last century, environmental problems were often considered local problems due to the impact from a certain product. However, today it becomes more obvious that the problems are much more complex and related to all the phases in a products life cycle, from extraction of material to waste or deposition of the used product (Berkhout and Smith, 1999). The dairy industry is one example of a factory characterized by the association of different production systems such as agriculture, livestock, dairy farming, dairy packaging and product distribution. These systems are closely intertwined, since the final product quality is highly dependent on the appropriate combination between the systems reported (Hospido *et al.*, 2003).

Aerobic treatment processes are commonly used together with anaerobic processes for dairy wastewater treatment, in order to achieve the effluent discharge limits for agro-industry wastewaters (Demirel *et al.*, 2005). On the other hand, the physical/chemical methods that have proven to be successful are coagulation/flocculation (Feofanov and Litmanova, 2001), nanofiltration (NF) and reverse osmosis (RO) membranes (Turan, 2004) and membrane bioreactor (MBR) systems (Bae *et al.*, 2003).

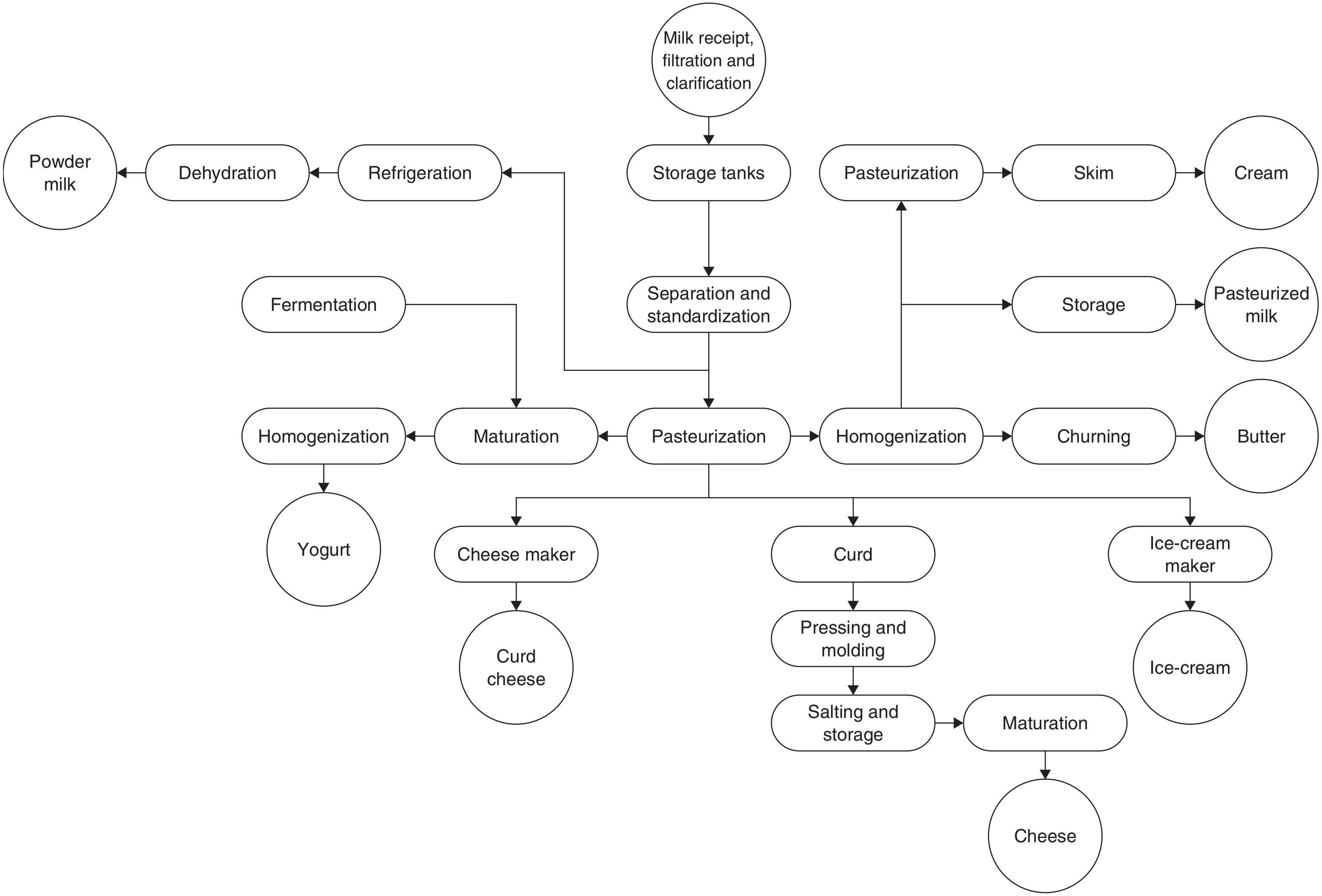

Figure 13.1 Flow diagram of various processes occurring at a typical milk plant (http://www.agrifood-forum.net/publications/guide/d_chp2.pdf; http://www.fao.org.wairdocs/LEAD/X6114E/x6114e06.htm; http://www.edibon.com/products/catalogues/en/systems/pilotplants/LE00.pdf)

Treatment methods

Dairy wastewater is characterized by the high biological oxygen demand (BOD) and chemical oxygen demand (COD) contents, high levels of dissolved or suspended solids including fats, oils and grease, nutrients such as ammonia or minerals and phosphates and therefore require proper attention before disposal (Sarkar *et al.*, 2006). The processes used nowadays for dairy waste treatment are the following: aerobic treatment, anaerobic treatment, membrane treatment, constructed wetlands, coagulation/electrocoagulation/flocculation/precipitation, bioremediation and miscellaneous treatment methods.

Aerobic treatment

Conventional treatment of dairy wastewater involves aerobic processes, since fats, lactose and proteins are all easily degraded by bacterial populations (Samkutty *et al.*, 1996). Aerobic treatment is an effective alternative for removing odor. Aerobic treatment consumes large quantities of energy and has higher operating and maintenance costs. However, aerobic treatment has lower capital costs than anaerobic digestion and it is less effective in recovering nutrients than anaerobic digestion (http://www.makinganergy.com/Dairy%20Waste%20Handbook.pdf).

Two different reactor systems, thermostated at 30°C, were used for aerobic purification of dairy wastewater. The first system (system I) was a single reactor with a working volume of 80 l, while the second one (system II) was a three-stage reactor cascade with a total working volume of 30 l. The minimum operation time for system I was 30 days and, for system II, 50 days. An overload of system I was recorded when the load was higher than 0.741 kg/m^3 COD/day, while the system efficiencies were higher than 96.8% and pH values were stabilized. In system II, treatment efficiencies were higher than 98.5% and total chemical oxygen demand (TCOD) and soluble chemical oxygen demand (SCOD) were reduced up to 50 and 70%, respectively. In both systems, minimum organic matter removal was 82%, when loads were lower than 1 kg/m^3 COD/day (Carta-Escobar *et al.*, 2004).

Anaerobic treatment

Over the past 25 years, anaerobic digestion processes have been developed and applied to a wide array of industrial and agricultural wastes (http://www.makinganergy.com/Dairy%20Waste%20Handbook.pdf). Anaerobic digestion has become an option for sustainable treatment of livestock manure, converting it to biogas and effluent. Digested effluent from anaerobic digestion of livestock manure usually contains high strength ammonium nitrogen (NH_4-N) and persistent organic substances. The components of digested effluent were applied as fertilizer for nutrient recycling back to agricultural fields (Salminen *et al.*, 2001; Umetsu *et al.*, 2002).

Dairy wastewater was treated in upflow anaerobic sludge blanket (UASB) reactors by Ramasamy *et al.* (2004). Two types of UASB reactors were used, anaerobic sludge

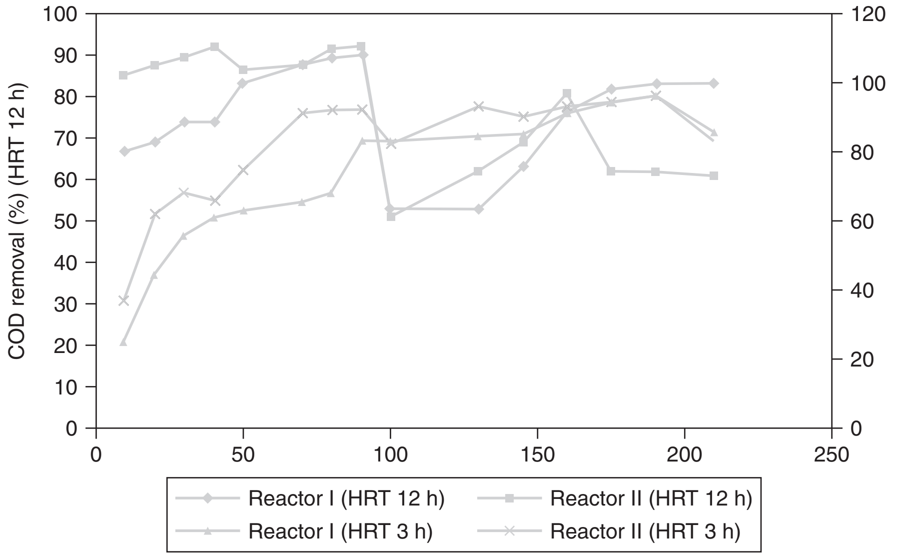

Figure 13.2 COD reduction (%) of synthetic dairy waste treated in two types of UASB reactors (reactors I and II) at two different hydraulic retention times (HRTs) (3 and 12 h) (adapted from Ramasamy *et al.*, 2004)

granules from digested cow dung slurry (DCDS) (reactor I) and granules obtained from the reactors treating sugar industry wastewaters (reactor II) and operated at hydraulic retention times (HRT) of 3 and 12 h and on COD loading rates 2.4–13.5 kg/m^3 of digester volume/day. The results indicated that 95.6 and 96.3% maximum COD reduction occurred at HRT of 3 h in reactors I and II, respectively. When the HRT was 12 h, the COD reduction was 90 and 92% in reactors I and II, respectively (Figure 13.2). In both reactors, the maximum, second best and the third best COD reduction was reported at loading rates of 10.8, 8.6 and 7.2 kg/m^3/day, respectively, whereas at loading rates higher of 10.8 kg/m^3/day the reactors' performance dropped. Better biodegradation of the waste was reported in the first few months of both reactors' operation.

A high-rate anaerobic reactor was developed for treating dairy effluent without fat removal pretreatment. After 400 days of reactor operation, 90% of COD was removed at an organic loading rate of 10 COD/m^3/day, while COD recovery as methane was close to 100% (0.37 l CH_4/g COD removed). Furthermore, scum accumulation and degradation were observed before stable methanation, whereas complete degradation of scum was recorded when the reactor was unfed (starvation tests). The nature of produced scum changed from hydrophobic (fat) to hydrophilic. On the other hand, loss of enzyme activity was reported during starvation tests of 1–2 weeks, as solids solubilization activity was lost and scum accumulation and degradation occurred. The microbial sludge obtained after starvation tests was in the form of irregular granules and did not require selection pressures caused by washout of poor settling flocs (Haridas *et al.*, 2005).

The anaerobic on-site treatment of synthetic black water (BW) (tap water, toilet paper and primary sludge from a municipal wastewater treatment plant) and dairy parlor wastewater (DPWW) in UASB-septic tanks at low temperatures (10–20°C) for 398 days was

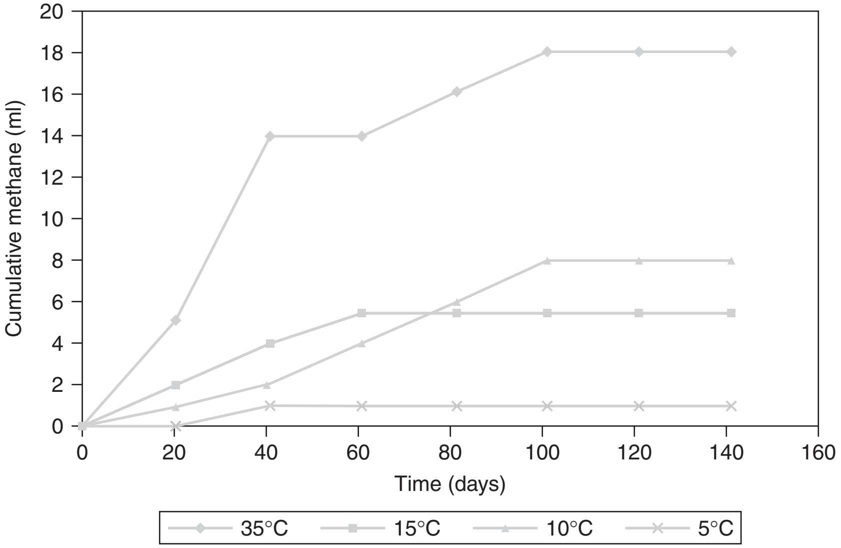

Figure 13.3 Cumulative methane production of sludge from dairy parlor wastewater at various temperatures (adapted from Ferchichi *et al.*, 2005)

investigated by Luostarinen and Rintala (2005). The results indicated 80% and 90% total chemical oxygen demand (TCOD) removal for BW and DPWW, respectively, while above 90% total suspended solids (TSS) removal for both wastewaters was recorded. Furthermore, dissolved COD (DCOD) and BOD_7 removal was approximately 70% and 93%, respectively, for both wastewaters. In both sludges, cumulative methane production was highest at 35°C and decreased with decreasing temperature (Figure 13.3). A single-phased reactor for BW and a two-phased system for DPWW treatment were proven to be sufficient for good COD and solids removals. BW nutrient removal was high, as nutrients were attached to TSS and removed with solids, while DPWW nutrient removal was considerably low. Conclusively, the UASB-septic tank was found efficient for pretreatment of BW and DPWW at low temperatures (Luostarinen and Rintala, 2005).

Three parallel two-stage anaerobic sequencing batch reactor (ASBR) systems (I, II and III), each consisting of two ASBR in series, were operated for dairy wastewater treatment. Two thermophilic (55°C)–mesophilic (35°C) ASBR systems (systems II and III) with 1:4 and 1:2 volume ratios, respectively, and one mesophilic (35°C)–mesophilic (35°C) ASBR system with 1:4 volume ratio were fed with dairy manure and run at two hydraulic retention times (HRTs) (3 and 6 days) and five volatile solids (VS) loading rates (2, 3, 4, 6 and 8 g/l/day). A high solid retention time (SRT) of 13–18 days was applied at both HRTs for all three systems, whereas at HRT of 3 days and at VS loading rates of 6 g/l/day all systems performance deteriorated. At systems operation at HRT of 3 days, the ideal VS loading rates were 2–4 g/l/day. Furthermore, VS removal ranged from 26.1 to 44.2% and specific methane production from 0.2 to 1.6 l/l/day for the three systems. The produced biogas contained 62–66% CH_4 and 28–31% CO_2. An increase up to 37% in NH_3-N in treated wastewater was observed, while the systems with thermophilic reactors were found to be highly effective in destroying the total coliforms (Dugba and Zhang, 1999).

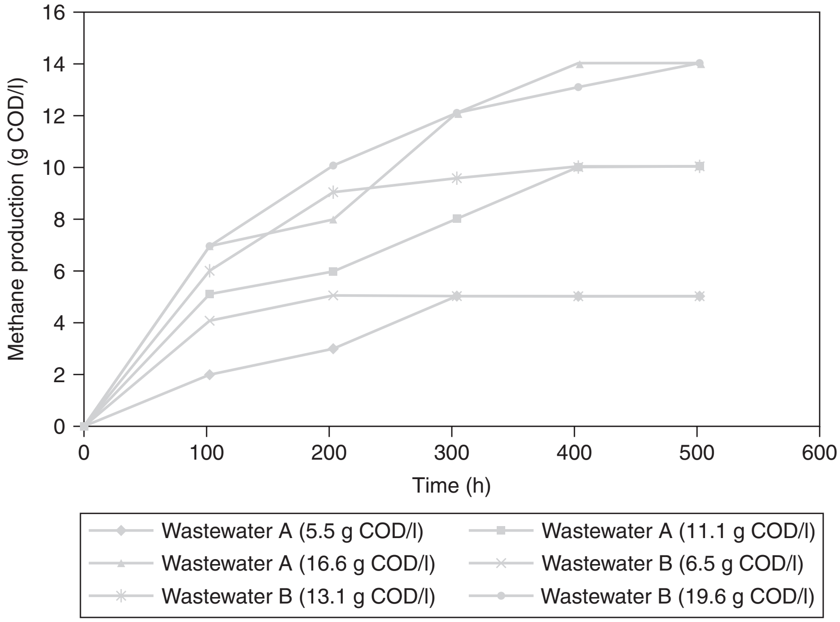

Figure 13.4 Methane production from different effluents (g COD/l) (adapted from Vidal *et al.*, 2000)

Vidal *et al.* (2000) examined the potential effects of fat and protein content on the anaerobic biodegradability of dairy wastewater. Two types of wastewater compositions with total COD 0.4–20 g/l were used for anaerobic biodegradability batch assays, the first obtained by dissolving full cream milk powder (25.4% proteins, 38.9% sugars and 26.0% fats – wastewater A) and the second recovered from skimmed milk powder (33.9% protein, 52.1% sugars and 0.9% fat – wastewater B). At lower concentrations (1–5 g COD/l) biodegradability and methanization were greater in fat-rich wastewater (wastewater A). At higher concentrations (5–20 g COD/l) the biodegradability of wastewater A varied from 98 to 99%, while wastewater B declined from 97.5% down to 86%. Methane production in wastewater B increased linearly with COD increase, in comparison to wastewater A where methane production rate increased only at low COD (<5 g/l) and not at higher concentrations (>6 g COD/l) (Figure 13.4). Furthermore, total volatile fatty acids (VFA) accumulation was observed at higher COD concentrations (5–20 g COD/l), and free ammonia concentration was high (60 mg/l) in wastewater B at high COD values (20 g/l).

Five laboratory-scale mesophilic UASB reactors were fed with dairy wastewater and operated with different intermittent cycle lengths, from 24 to 144 h, and loads between 2.5 and 29.0 g COD/l/day. For each cycle there was a feed and feedless period, which had the same duration (i.e. half the cycle length). The amount of methane produced in the feedless periods was significantly higher compared to the total cycle production and ranged from 22 to 36% of the total methane produced in the whole cycle. Furthermore, COD removal varied between 96 and 98% for all reactors. The higher conversion of removed COD to methane rose from 59 to 85% and was

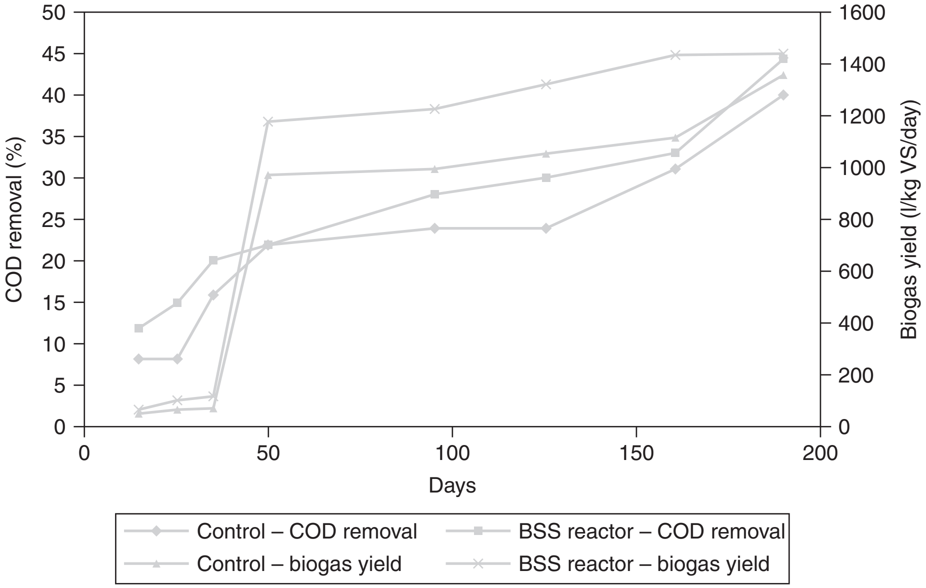

Figure 13.5 Comparison of start-up performance between conventional and BSS-ST reactors regarding COD removal and biogas production (adapted from Ramasamy and Abbasi, 2000; Arvanitoyannis and Giakoundis, 2005)

reported for the 96 h cycle (48 h feed and 48 h feedless period), while this cycle was considered as the optimum one for the treatment of dairy effluents in intermittent UASB reactors (Nadais *et al.*, 2005).

Ramasamy and Abbasi (2000) tried to upgrade the performance of a continuously-stirred tank reactor (CSTR) by incorporating a biofilm support system (BSS). Mixed liquor (synthetic dairy waste, fresh cow-dung slurry, digested cow-dung slurry), which was then replaced with exclusive dairy waste, was used as an initial feed in the reactor with HRT of 15 days. As soon as the feeding of the reactor began, the biogas production also started in both the normal (served as control in their experiments) and BSS reactor. COD and pH reduction of the effluent was found to be low, but when dairy waste was the only feed composition substrate, biogas yield and pH increased. A greater COD reduction was also reported in the BSS reactors than in the conventional ones. Volatile solids (VS) decline was found to be 60% in the BSS reactors and only 40% in the control when the HRT was reduced to 10 days. The biogas released by both reactors varied from 56 to 58% (Figure 13.5).

Membrane treatment

With the advent of membrane technology and significant improvements in efficiency and cost-effectiveness, the competitiveness of recycling dairy wastewater over discharge has greatly increased (Sarkar *et al.*, 2006). Several membrane operations have been proposed for the treatment of dairy effluents: one-stage operations like ultrafiltration (UF) (Blanchard, 1991), nanofiltration (NF) (Koyuncu *et al.*, 2000), reverse osmosis (RO)

(Delbeke, 1981), or two-stage operations like UF + RO (Argellier and Pannuzzo, 1999), NF + NF (Mavrov *et al.*, 2001) and RO + RO (Koyuncu *et al.*, 2000).

Different nanofiltration (NF) and reverse osmosis (RO) membranes for dairy effluent treatment by dead-end filtration were investigated by Balannec *et al.* (2005). Skimmed milk diluted with water (dilution 1/3) (COD $\approx$ 36 g O_2/l) was concentrated to 1/1 milk (volume reduction factor, VRF 3) using nine NF and RO membranes at 25°C, pressure 1.5 MPa (for NF membranes) and 2.5 MPa (for RO membranes), and stirring velocity 100 rpm. High COD, lactose and citrate, bound to Ca^+, Mg^+ and micellar casein, removal up to 98.9–99.8%, 98.2–99.8%, and above 99.9%, respectively was observed in the permeate at different membranes and feed concentration. Conductivity rejection to NF and RO membranes was 33–80% and around 96%, respectively, thus showing that treated water cannot be used as a boiler feed water. In NF membranes, divalent cation rejection was above 90%, while negative rejection of Cl^- (-26 to -80%) at VRF 3 was recorded. At VRF 3, COD of permeate was not suitable for human consumption (total organic carbon, TOC $<$ 2 mg/l), even though RO permeate can be released as waste.

By-products from ovine cheese manufacture (ovine cheese whey and deproteinized whey) were submitted to two treatments: conventional ultrafiltration (UF) (Treatment I) and thermocalcic precipitation–microfiltration (TP/MF) using two MF membranes (0.65 and 0.20 mm pore size) followed by UF and diafiltration (UF/DF) (Treatment II) (Figure 13.6). The clarification of ovine cheese by-products by TP/MF improved posterior UF treatments significantly. At 0.65 mm pore size of MF membranes, the clarification was more effective and, as well as the obtained product, had high protein content and can be used in the food industry. At 0.20 mm pore size of MF membranes, poor flux performance and high degree of protein retention were reported, thus indicating that MF membranes with pore size 0.65 mm stand for the ideal choice for clarification of ovine cheese by-products (Pereira *et al.*, 2002).

A hollow fiber membrane bioreactor was operated for enzymatic lactose hydrolysis in skimmed milk by Novalin *et al.* (2005). Skimmed milk was pumped through the hollow fiber module and, before enzymatic conversion, was passed over a heat exchanger, a manometer and a thermometer. At the end of the module, the lactose-hydrolyzed product was collected. The enzyme (β-galactosidase) was pumped in a closed circulation and due to the microbiological growth a UV irradiation module and a sterile filtration unit were included in the enzyme circulation. Lactose conversion in skimmed milk rate decreased from 92.48% at flow rate of 5.04 l/h to 78.11% at 9.9 l/h, at enzyme activity of 120 U/ml and a temperature of 23 ± 2°C in a hollow fiber reactor with a membrane area of 4.9 m^2.

The use of a ceramic microfiltration (MF) membrane for the fractionation of regular and whey buttermilk, using two different filtration modes, volumetric concentration (VC) and diafiltration (DF), was studied by Morin *et al.* (2006). The experiment was carried out at low temperature (8–10°C) at a transmembrane pressure of 80–95 kPa. The DF process included a significant decrease in protein transmission through the membrane for regular and whey buttermilk (19.5% and 25%, respectively), in comparison to the VC process where protein transmission also decreased for whey buttermilk (33.0%). In the DF process, a decline in ash transmission for regular buttermilk (65.5%) and an increase in phospholipids transmission for regular

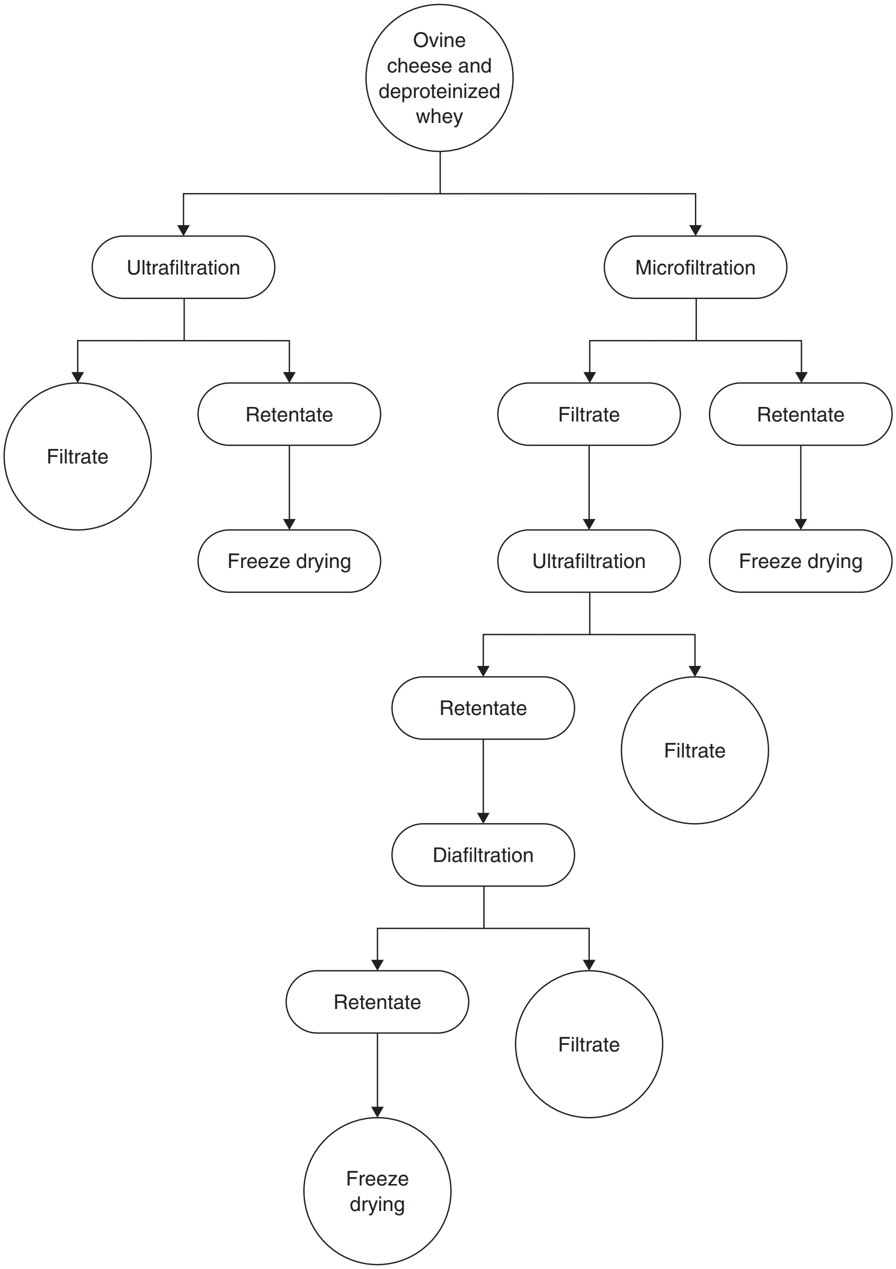

Figure 13.6 Process diagram of conventional ultrafiltration (UF) and thermocalcic precipitation–microfiltration of ovine cheese by-products (adapted from Pereira *et al.*, 2002)

buttermilk (39.1%) were reported. During the DF process, regular buttermilk doubled its phospholipid content, whereas that of whey buttermilk increased by 50%. In the VC process, total lipids transmission was 5.8% and 3% for regular and whey buttermilk, respectively, whereas in the DF process, transmission of lipids for regular and whey buttermilk was higher (8.5% and 4.7%, respectively).

Frappart and coworkers (2006) treated dairy process waters, modeled by diluted milk, using dynamic nanofiltration with a rotating disk module. Skimmed milk, diluted 1:2 with initial, was fed in a filtration system consisting of a metal disk (smooth or with radial vanes) rotating at high speed near a flat circular membrane operated at a transmembrane pressure (TMP) of 4000 kPa, at 45°C and at rotation speeds of 1000 and 2000 rpm. Concentration tests were also conducted at both types of disks, at TMP of 2000, 3000 and 4000 kPa, at 45°C and at rotation speed of 2000 rpm. At TMP of 4000 kPa and 2000 rpm (with vanes), permeate flux decreased up to 56.5% with increasing volume reduction ratio (VRR) from 1 to 7.5. The maximum dry matter percentage was 38% and obtained using a disk with vanes rotating at 2000 rpm. Permeate COD and mean ionic concentration increased with increasing VRR values at 2000 rpm irrespective of disc type, while COD was higher with smooth disks than disks with vanes.

Constructed wetlands

Constructed wetlands treatment involves a sediment retention and nutrient removal treatment system that uses natural chemical, physical and biological processes involving wetland vegetation, soils and their associated microbial populations to improve water quality (http://www.sera17.ext.vt.edu/Documents/BMP_Constructed_Treatment_Wetlands.pdf). 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 and low energy input requirements after construction (Hammer, 1992).

Moir *et al.* (2005) treated wastewater derived from a dairy parlor, by means of a multiple-phase biological system. The system consisted of an aerated sequencing batch reactor (SBR) containing activated sludge, followed by a series of constructed wetlands. The wetland sequence was composed of one subsurface horizontal flow reedbed, followed by three banks of vertical flow reedbeds in series. In the SBR, a significant decrease of BOD_5 and COD up to 92.1–96.1% and 86.1–89.5%, respectively occurred. Treated wastewater in the wetlands exhibited reduced values in BOD_5 and COD ranging from 70.1 to 81.8% and from 56.6 to 64.5%, respectively. A substantial reduction in suspended solids (SS), ammonium, nitrate and phosphorus concentrations in treated wastewater was reported.

Tanner *et al.* (1995a, b) conducted two experiments in order to examine the effect of loading rate and planting on oxygen demand, suspended solids (SS), fecal coliforms (FC) (Tanner *et al.*, 1995a), total nitrogen (TN) and total phosphorus (TP) (Tanner *et al.*, 1995b) removal of dairy farm wastewaters in constructed wetlands. Four pairs of planted (*Schoenoplectus validus*) and unplanted gravel-bed wetlands were operated at retention times of 7, 5.5, 3 and 2 days, with in- and outflows sampled bimonthly for 20 months (Tanner *et al.*, 1995a, b). Influent water quality varied markedly over the trial period (carbonaceous biochemical oxygen demand ($CBOD_5$): 20–300 g/m^3; SS: 60–250 g/m^3; FC: 103–104 MPN/100 ml; TN: 10–110; NH_4-N: 5–70; and TP: 8–18 g/m^3) (Tanner *et al.*, 1995a, b). $CBOD_5$ removal was up to 76–92% and 60–85% in planted and unplanted constructed wetlands, respectively. In planted channels BOD ($CBOD_5$ + NBOD) removal decreased from 80 to 50% at high loading rates, whereas in unplanted wetlands BOD removal ranged from 60 to 85%. Furthermore, 75–80% SS and 90–99% FC removal was recorded for both planted and unplanted wetlands. Dissolved humic color in the wastewaters was not really affected at short retention times and reduced up to 40% at longer retention times (Tanner *et al.*, 1995a). On the other hand, TN removal in planted and unplanted channels was 48–75% and 12–41%, respectively and TP removal was 37–74% and 12–36%, respectively (Tanner *et al.*, 1995b).

An ecological treatment system (ETS) was applied for nutrients removal from dairy wastewater. The wastewater flowed through the anaerobic reactor, anoxic reactor, closed aerobic reactor, planted aerobic reactor, clarifier, subsurface wetland mesocosm, two more planted aerobic reactors and another clarifier and two more subsurface wetland mesocosms for 20 weeks prior to being discharged. The results showed 99% removal of ammonium-nitrogen (NH_4-N) and carbonaceous biochemical oxygen demand (CBOD) and 79% removal of orthophosphate (PO_4-P). Furthermore, nitrate and nitrite were also produced with effluent concentration of 0.53 mg/l, but removed effectively within the system. Therefore, ETS enhanced biological removal of nitrogen and phosphorus from dairy wastewater (Lansing and Martin, 2006).

A constructed wetland system consisting of two settling basins, two wetland cells planted with *Typha latifolia* L. and *Schoenoplectus tabernaemontani* and a vegetated filter strip colonized by *Lemna minor* L. and *Echinochloa crus-galli*, was operated for dairy wastewater treatment. The results indicated a significant reduction of total nitrogen (98%), ammonia (56%), total phosphorus (96%), ortho-phosphate (84%), suspended solids (96%) and biochemical oxygen demand (97%). On the contrary, nitrate/nitrite increased by 82%, due to the oxidation of ammonia via nitrification in the vegetated filter strip (Schaafsma and Baldwin, 1999).

Coagulation/electrocoagulation/flocculation/precipitation

Coagulation/flocculation is one of the most important physicochemical treatment steps in industrial wastewater treatment to reduce the suspended and colloidal materials responsible for turbidity of the wastewater and also for the reduction of organic matter which contributes to the BOD and COD content of the wastewater (Rossini *et al.*, 1999; Al-Mutairi *et al.*, 2004). On the other hand, electrocoagulation has been very successfully employed in removing oil/grease and SS from a variety of industrial effluents (e.g. oil refinery waste) (Chen *et al.*, 2000; http://www.esemag.com/index.html) and is a combined coagulation and flotation process induced by the passage of electric current.

Şengil and Özacar (2006) looked into the potential of treating wastewater obtained from a dairy factory using direct current electrocoagulation. The effect of initial pH (3.5–10.0), electrolysis time (1–6 min), initial concentration of COD (1550–19 800 mg/l), conductivity (0.77–4.61 mg/l) and current density (0.3–1.8 mA/cm^2) on COD and oil-grease concentration were also studied. The experiment was conducted in an electrochemical reactor consisting of iron electrodes at 25°C, 0–15 V and 0–3 A. COD and oil-grease removal up to 98% and 99%, respectively, were reported. The optimum current density, pH and electrolysis time for treating dairy wastewater with COD of

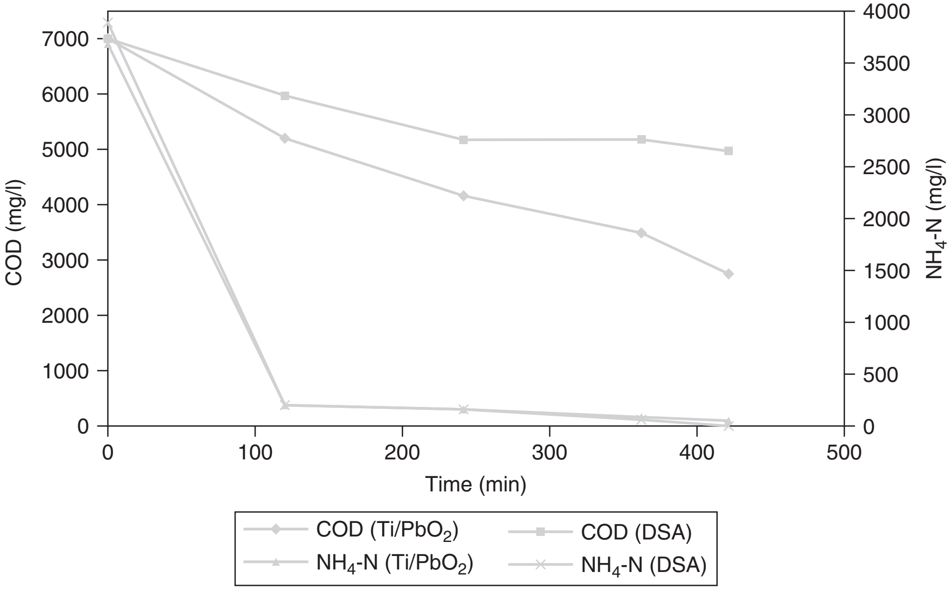

Figure 13.7 Decrease of NH_4-N and COD during electrochemical oxidation of dairy manure (adapted from Ihara *et al.*, 2006)

18 300 mg/l and oil-grease of 4570 mg/l were 0.6 mA/cm^2, 7 and 1 min, respectively, while energy consumption was estimated at 0.003 kWh/kg of COD.

The electrochemical oxidation of the effluent from anaerobic digestion of dairy manure was investigated by Ihara *et al.* (2006). The digested effluent obtained from a full-scale anaerobic digester was pretreated with membrane filters for suspended solids (SS) removal, prior to electrochemical oxidation experiments. Direct anodic oxidation and indirect oxidation were evaluated through the use of a dimensionally stable anode (DSA) and lead dioxide coated titanium (Ti/PbO_2) as anode and stainless steel as cathode. The results showed that the decreasing rate of NH_4-N was higher at the DSA than Ti/PbO_2 anode, whereas the decreasing rate of COD was higher at the Ti/PbO_2 than the DSA anode (Figure 13.7). Moreover, the electrochemical oxidation with DSA prevented the accumulation of NO_3-N. NaCl addition to the sample before membrane filtration considerably increased the decreasing rate of NH_4-N.

The effluents from two different anaerobic reactors for dairy manure (one- and two-phase) were subjected to struvite precipitation to remove ammonia nitrogen. Struvite is a white crystalline solid formed according the following reaction: $Mg^{2+} + NH_4^+ + PO_4^{3-} + 6H_2O \rightarrow MgNH_4PO_4{\cdot}6H_2O$. Struvite precipitation experiments were conducted in continuously stirred batch reactors at room temperature (21–22°C) by adding Mg^{2+} in the form of $Mg(OH)_2$ and $MgCl_2{\cdot}6H_2O$. The results indicated that ammonia (NH_4^+) removal above 95% can be achieved by adding 0.06 M Mg^{2+} to the effluents obtained from one- and two-phase reactors. $MgCl_2{\cdot}6H_2O$ proved to be more effective in NH_4^+ removal than $Mg(OH)_2$, while less Mg^{2+} was required in the effluent from a two-phase reactor to achieve similar removal efficiencies compared to the effluent from a one-phase reactor (Uludag-Demirer *et al.*, 2005).

Table 13.2 Dairy wastewater analysis during membrane processing in laboratory and pilot scale studies

	After chitosan (10 mg/l)		After PAC (1.5 g/l)		MF permeate		RO permeate	
	Laboratory scale	Pilot scale	Laboratory scale	Pilot scale	Laboratory scale	Pilot scale	Laboratory scale	Pilot scale
TDS (mg/l)	260–440	470	100–200	360	–	300	57–90	33
COD (mg/l)	203–583	295	203–388	197	–	197	81–117	16.5
BOD (mg/l)	–	520	–	440	–	85`	–	8

Adapted from Sarkar *et al.*, 2006

Wastewater derived from a dairy farm was subjected to coagulation with inorganic (alum and ferric chloride), polymeric (polyaluminium chloride) and natural organic (sodium carboxymethyl cellulose, alginic acid and chitosan) coagulants, followed by powdered activated charcoal (PAC) treatment and pH adjustment to 6.5. Laboratory-scale experiments were then conducted and the wastewater went through ultrafiltration (UF) and reverse osmosis (RO) membranes separately. Pilot-scale studies were also performed and the water went through microfiltration (MF) and RO membranes. The results revealed that the optimized conditions for wastewater treatment were with 10 mg/l chitosan, 1.5 g/l dosage of PAC and pH adjustment to 4.0. Under these conditions, 57% total dissolved solids (TDS) and 62% COD reduction were reported, while the color and the odor had been eliminated. In laboratory-scale studies, TDS and COD decrease were not significant after ultrafiltration, even though a 90.8–91.8% TDS decrease and 80–91% COD removal was observed in the RO permeate. In pilot scale studies, TDS, COD, and BOD removal of RO permeate was 95.8%, 98.5% and 95.8%, respectively (Table 13.2). The quality of water after reverse osmosis was comparable to that of dairy process water and can be recycled back (Sarkar *et al.*, 2006).

Bioremediation

Bioremediation is the naturally occurring process through which microorganisms either immobilize or transform environmental contaminants to innocuous end products (Thassitou and Arvanitoyannis, 2001). Successful treatments of dairy effluent through bioremediation and its safe release into the water or environment have been developed in Hungary (Kis and Ujhelyi, 1988; Szego, 1988; Kis, 1993), India (Venkataraman *et al.*, 1988a, b; Mehadia and Ingle, 1995), Ireland (Fallowfield and Garrett, 1985), Italy (Felice and Scioli, 1994), Japan (Hayashi *et al.*, 1984), Spain (Mateos *et al.*, 1986) and The Netherlands (Mulder *et al.*, 1982). The basic objective of treating the dairy effluent is to reduce its adverse impact on flora and fauna. The success of any treatment including bioremediation, however, depends on the choice of a suitable agent in the correct place under the proper environmental conditions (Mishra *et al.*, 2000).

The nutrient removal capacity of three aquatic macrophytes, such as *Eichhornia crassipes*, *Lemna minor* and *Azolla pinnata*, and their combination was investigated by

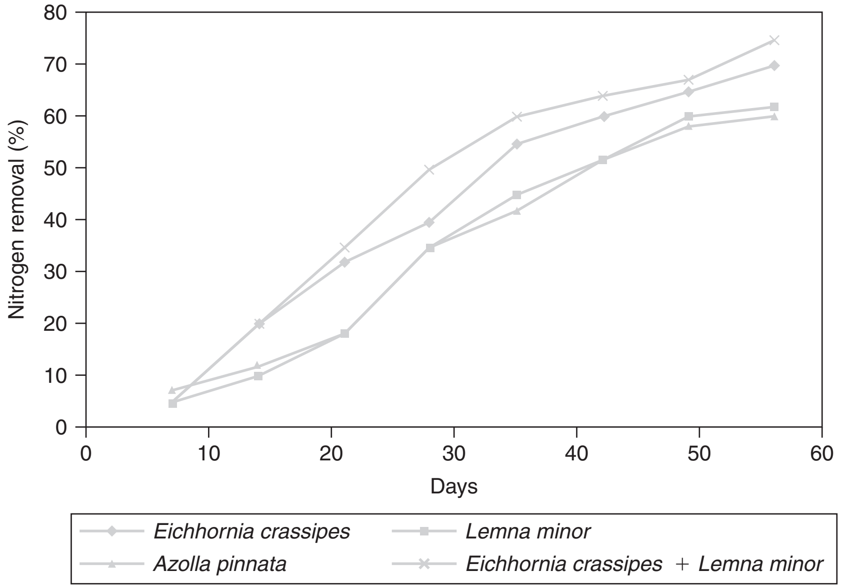

Figure 13.8 Nitrogen removal by aquatic macrophytes (individually and combination) (adapted from Tripathi and Upadhyay, 2003)

Tripathi and Upadhyay (2003). All three plants were cultured individually (monoculture) with 100% cover and in combinations, and then placed in separate aquaria. Each aquarium was filled with dairy effluent, while control experiments were also performed using dairy waste without any macrophyte. Nitrogen (N) removal by *E. crassipes*, *Lemna minor* and *Azolla pinnata* was 71.8%, 62.5% and 60.1%, respectively. On the other hand, phosphorus (P) removal by *E. crassipes*, *Lemna minor* and *Azolla pinnata* were 63.2%, 58.8% and 56.3%, respectively. The highest removal of N (78.8%) and P (69.4%) was reported in mixed culture of *E. crassipes* and *L. minor*. An increase in N and P content in plant tissues was also reported (Figures 13.8 and 13.9).

The potential of cellulase/β-glucosidase production by a mixed fungi culture of *Trichoderma reesei* and *Aspergillus phoenicis* on dairy manure was investigated by Wen *et al.* (2005). Dairy manure (at different concentrations) supplemented with 2 g/l KH_2PO_4, 2 ml/l tween-80 and 2.0 mg/l $CoCl_2$ was inoculated with pure culture of either 10% (v/v) *T. reesei* (25.5°C and pH 5.76) or 10% (v/v) *A. phoenicis* (28.2°C and pH 5.14). For mixed culture, 10% (v/v) *T. reesei* and 10% (v/v) *A. phoenicis* were inoculated in manure at 27.8°C and pH 5.5. Cellulase with a high level of β-glucosidase was produced in the mixed culture of *T. reesei* and *A. phoenicis* (Figure 13.10). Additionally, β-glucosidase activity and filter paper activity were 0.64 IU/ml and 1.54 FPU/ml, respectively. The glucosidase concentration produced was considerably higher than that produced over manure treatment with commercial enzyme and enzyme broth of the pure culture of *T. reesei*.

Sugarcane trash and cattle dung were blended at different proportions (4:1 or 1:1 dry weight basis) and the blend was turned after 14, 30, 45, 60 and 90 days, while moisture was maintained at 60% of water-holding capacity (WHC) and the temperature

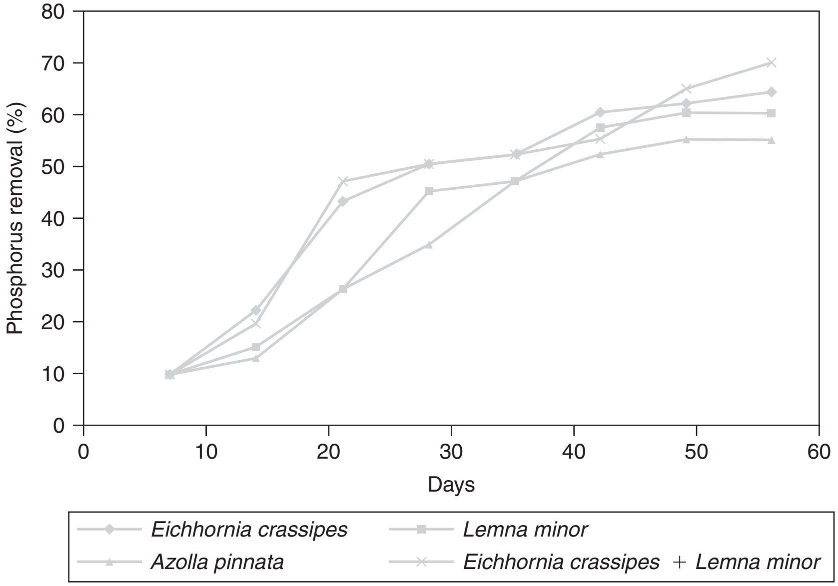

Figure 13.9 Phosphorus removal by aquatic macrophytes (individually and combination) (adapted from Tripathi and Upadhyay, 2003)

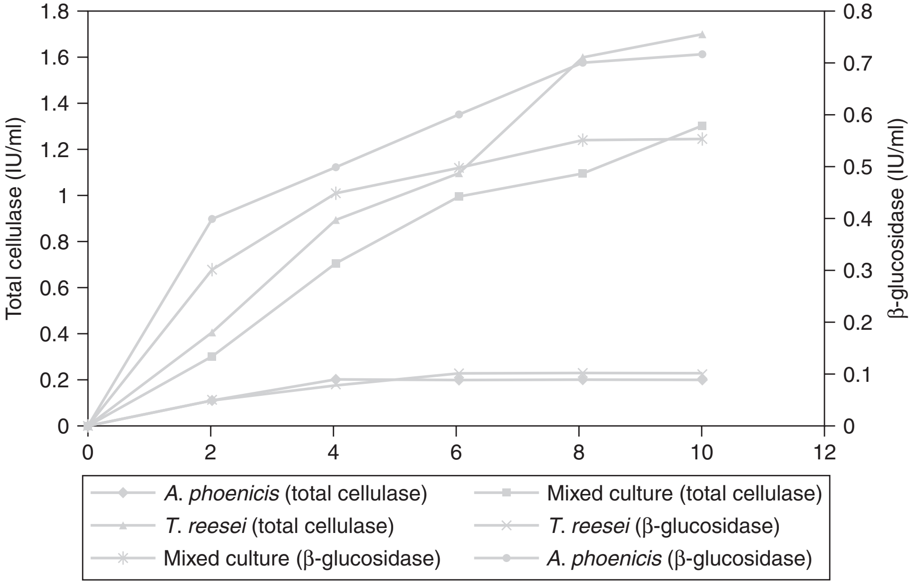

Figure 13.10 Total cellulose and β-glucosidase production by pure culture of *T. reesei* and *A. phoenicis* and the mixed culture of both fungi (adapted from Wen *et al.*, 2005)

ranged from 28–30 to 45°C. The results revealed that organic carbon and C/N ratio decreased with time, whereas total nitrogen content increased with time. Maximum enzyme activities for cellulase, xylanase and protease were reported after 30 and 60 days of composting. The population of thermophilic and mesophilic bacteria was

Table 13.3 Changes in organic C, total N, C:N ratio, cellulose, xylase protease activity and mesophilic and thermophilic population during composting of cattle dung waste

	Sugarcane trash and cattle dung (4:1)					Sugarcane trash and cattle dung (1:1)				
(days)	0	14	30	60	90	0	14	30	60	90
Organic C (%)	47.5	–	44.1	43.0	41.3	48.0	–	44.7	43.8	38.9
Total N (%)	0.9	–	1.2	1.4	1.4	1.5	–	1.5	1.7	1.9
C:N ratio	51.1	–	36.1	30.3	28.3	32.0	–	29.2	25.6	20.5
Cellulase activity (mg reducing sugar/ kg dry matter/h)	8.0	–	103.0	81.0	36.0	26.0	–	197.0	123.0	51.0
Xylase activity (mg sugar/kg dry matter/h)	22.0	–	42.0	53.0	30.0	16.0	–	65.0	83.0	51
Protease activity (mg tyrosine/ kg dry matter/h)	159.0	–	1030.0	1520.0	1183.0	309.0	–	717.0	1524.0	1198.0
Mesophilic bacterial population (10^7/g material)	13.8	24.0	207.0	75.0	72.0	9.8	21.2	215.0	114.0	84.0
Thermophilic bacterial population (10^5/g material)	6.0	50.4	8.0	1.8	0.6	2.0	88.2	24.0	2.4	1.2

Adapted from Goyal *et al.*, 2005

found to be highest at 14 and 30 days of composting, respectively and declined with time. On the other hand, the mesophilic fungal population had the highest value at 30 days of composting and decreased with time. The thermophilic population was reduced constantly during composting (Table 13.3) (Goyal *et al.*, 2005).

The ability of a commercial inoculum to degrade high fat content dairy wastewater aerobically was examined by Loperena *et al.* (2006). Industrial dairy wastewater with a high fat content (COD concentration 0.5–4 g/l) was fed into a batch mode bioreactor at pH 7, 30°C and 200 rpm. Moreover, continuous mode experiments were conducted using either industrial effluent or model effluent consisting of homogenized whole milk (COD concentration 0.5–1.9 g/l) at 19–23°C. During batch tests, COD removal was up to 78%, CO_2 production was 1.1 g/g of COD removed and biomass yield reached the level of 0.41 g volatile suspended solids (VSS)/g of COD removed. On the other hand, the COD removal amounted to 89% when the continuous mode bioreactor was fed with industrial wastewater.

Municipal solid wastes, such as mixed paper waste (old corrugated cardboard, printed office paper and old newsprint), food waste (milk, cooked pasta, hamburger, lettuce, raw potatoes and carrots) and yard waste (grass clippings and leaves), were composted individually or at different mixtures in an aerobic digester operated at 52 ± 2°C (thermophilic temperature) for 47–198 days. Partially composted municipal solid wastes were added to some runs and the experiment ended when carbon dioxide production rates dropped below 0.5 g CO_2-C/dry kg/day. The addition of partially composted municipal waste to paper or yard or food waste, each one composted individually, caused emission of 150, 220 and 370 g CO_2-C and 2.0, 4.4 and 34 g NH_3-N per dry kg of starting material, respectively. In all mixtures, the CO_2 emission ranged from 240 to 300 g CO_2-C per dry kg of initial substrate, while NH_3 production was 0.5–15 g NH_3-N per dry kg of initial substrate (Komilis and Ham, 2006).

Kosseva and his colleagues (2003) compared two bioremediation strategies of cheese whey treatment, using a mesophilic and thermophilic population of *Streptococcus* spp. and *Bacillus* spp., respectively. The first one consisted of an anaerobic, mesophilic (45°C) first stage, followed by an aerobic, mesophilic (45°C) second stage. The second one included an anaerobic, mesophilic (45°C) first stage, followed by an aerobic, thermophilic (55–65°C) second stage. The results indicated that dissolved oxygen (DO) was maintained at or above 80% of saturation during aerobic processing, whereas DO remained at above 65% of saturation during the thermophilic stage. COD decrease of whey during the anaerobic and aerobic stages was 68%, while soluble protein decline was up to 59%. Considering only the thermophilic treatment, the average decrease of COD and soluble protein was 62.5%, and 47.5%, respectively. In the mesophilic-thermophilic strategy, approximately 100% reduction of COD and lactose were reached, accompanied by a 90% decrease in soluble protein in batch cultures.

Miscellaneous treatment methods

A two-step hydrolysis of fibers from dairy manure involving concentrated acid decrystallization followed by dilute (less than 15%) acid hydrolysis was performed by Liao *et al.* (2006). Pretreated dairy manure with two nitrogen content levels (1.3% and 2.6%) was diluted to three different acid concentrations (65%, 70% and 75%) and used for concentrated acid hydrolysis experiments carried out at 100°C for 1 h at four treatment durations (30, 60, 90 and 120 min). Decrystallized manure was subject to acid hydrolysis under two acid concentrations (10% and 12.5%), three levels of temperatures (100, 120 and 135°C) and six reaction times (10, 20, 30, 60, 90, 120, 150 and 180 min). The optimal conditions for decrystallization were 75% acid concentration, 3:5 sample to acid ratio (weight basis) and 30 min reaction time; whereas the optimal conditions for acid hydrolysis were 12.5% acid and 10% dry sample at 135°C for 10 min. Under these conditions, 84% glucose (26 g/l) and 80% hemicellulose-sugars (11 g/l) were obtained.

Dairy manure was fed into the first (acidifying) reactor, operated for 26 days at an SRT/HRT of 10 days and organic loading rate (OLR) of 1.19 g COD/l day (1.0 g VS/l day). The obtained effluent was then fed to the second (methanogenic) reactor, run at the same OLR and influent VS concentration (0.91%) for 21 days. For the following 86 days, the two-phase reactor was operated at SRT/HRT of 10 days, at different OLR (2.39–15.06 g COD/l day or 2.0–12.6 g VS/l day, respectively) and influent VS concentrations (1.83–11.5%). Dairy manure was also fed into a conventional one-phase reactor at an SRT/HRT of 10 or 20 days at various OLR (0.96–3.01 g COD/l day or 1.0–3.15 g VS/l day, respectively) and influent VS concentrations (3.65–5.75%). In the two-phase reactor, the highest biogas production rate was 2.272 l/day at OLR of 7.53 g COD/l day, while the highest biogas yield was 1.76–1.78 l biogas/g VS added at OLR of 5.97 and 7.53 g COD/l day. Biogas production was 50% and 67% higher at

ORL of 5.97 and 7.53 g COD/l day, respectively, compared to conventional one-phase reactor with SRT/HRT of 20 days. Moreover, in the two-phase reactor, cost savings were significant due to superior performance and reduced volume requirements. In the two-phase reactor COD and VS removal was 30–71% and 16–70%, respectively. In the one-phase reactor at SRT/HRT of 20 days, a 45–77% COD and 36–70% VS decrease was reported and at SRT/HRT of 10 days, 24–50% COD and 16–40% VS decline was recorded (Demirer and Chen, 2005).

Flushed dairy manure was initially flowed down to a sand-trap, where some of the sand was recovered and used as bedding and then flowed to a mechanical separator for large fibrous solids removal. The separated wastewater was directed to a sedimentation basin and then into a sampling pit and a storage pond. Pretreated wastewater was pumped to an anaerobic lagoon, where the liquid was irrigated onto cropland. Solids removed with the mechanical separator and sedimentation basin were spread directly onto croplands (Figure 13.11). The results showed that, during wastewater screening and sedimentation, total solids (TS), volatile solids (VS) and total COD removal was up to 46.7%, 60.4% and 42.2%, respectively. Higher flushed dairy manure temperatures reduced TS, VS and total COD removal efficiencies. A substantial portion of the methane potential remains in the wastewater, due to removal of solids that are relatively non-degradable fibers and do not contribute to methane production (Wilkie *et al.*, 2004).

Organophilic clay, made from a smectitic clay with quaternary ammonium salt, was used to study the adsorption of the residual lactose which is not extracted from dairy industry effluents by conventional methods, by Morais *et al.* (2005). Lactose adsorption was studied at 30°C using aqueous concentrations from 200 to 1000 mg/l. The results indicated that the amount of lactose adsorbed by the organophilic clay was very small and ranged from 0.3 to 0.5%.

Danalewich *et al.* (1998) carried out an experiment to determine the effectiveness status of current dairy wastewater treatment practices and to estimate the potential for biological nutrient removal (BNR). In their study, 14 dairy industries, 12 of which produced one or more types of cheese and processed dairy whey as a secondary product, were included. Significant reduction in the volume of wastewaters produced per amount of milk processed, due to the increased plant size, the automation in product processing and the introduction of cleaning-in-place (CIP) systems over the last few decades were reported. However, the effectiveness/ineffectiveness of management strategies is still the critical factor determining the waste generation.

Table 13.4 provides a synoptic presentation of the most important treatment methods (parameters, quality control and results) of dairy industry waste.

Uses

Wastewater reclamation and re-use is currently of increasing interest in many parts of the world in response to a growing demand for reliable, high quality water supplies, particularly in drought-prone areas (Asano and Levine, 1996; Crook and Surampalli,

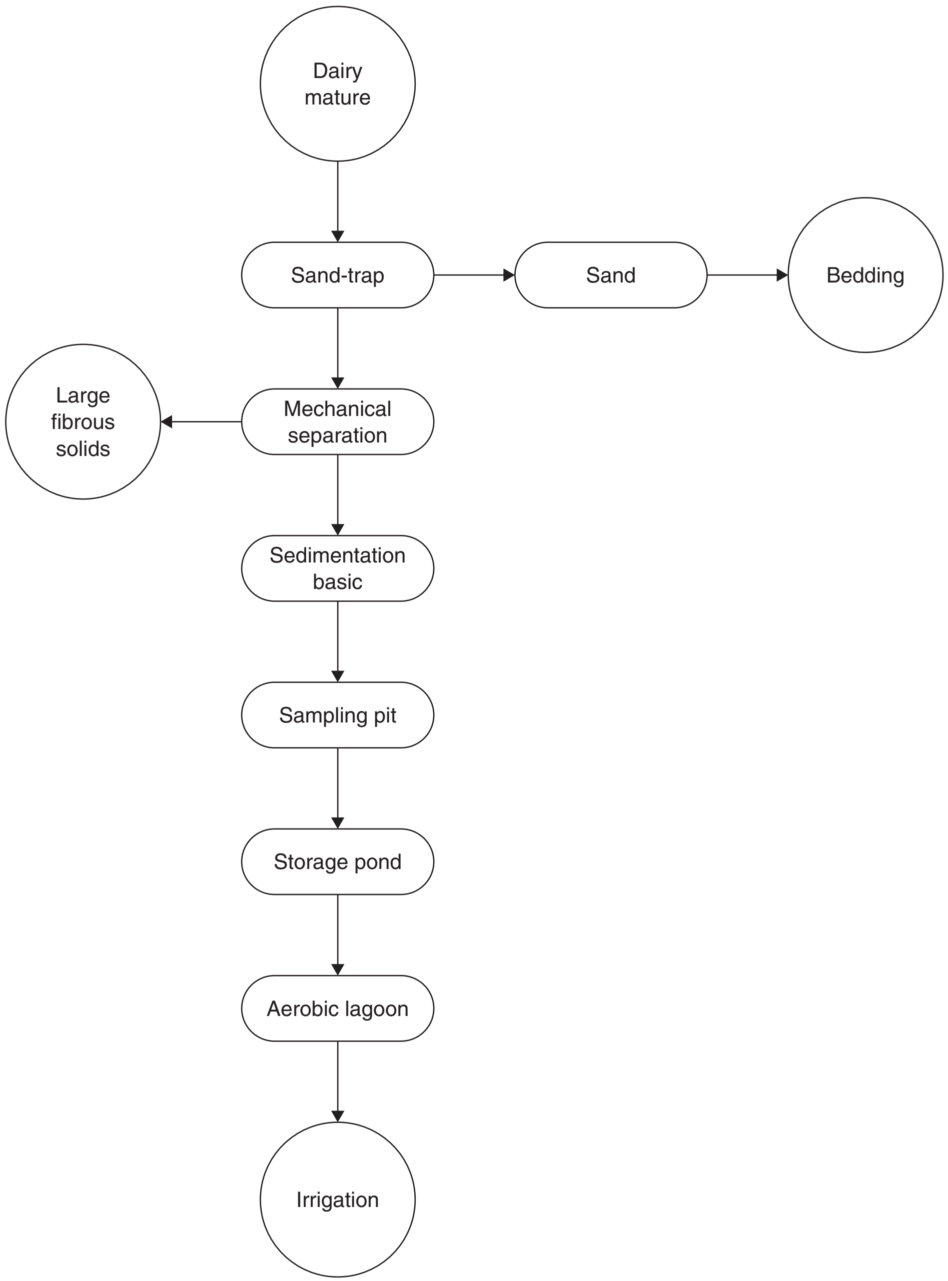

Figure 13.11 Fixed-film anaerobic digestion of flushed dairy manure after primary treatment (adapted from Wilkie *et al.*, 2004)

1996) and attention to integrated resource management and sustainability issues (Hermanowicz and Asano, 1999; Sala and Serra, 2004). Treated dairy waste has found many applications among which the most important are for biogas/biodiesel production, fertilizer, animal feedstuff, the food industry and miscellaneous uses.

Table 13.4 Treatment methodologies of dairy industry waste: parameters, quality control and results

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
A Aerobic treatment							
1	Wastewater	Aerobic purification	pH, TCOD, SCOD, TS, TSS, VSS, DO, SVI, biomass nitrogen content	The wastewater was first fed into a single reactor (30 days minimum operation time) and then into a three-stage reactor (50 days minimum operation time)	1 pH: pHmeter 2 TCOD, SCOD: filtering through a 0.45 m pore diameter membrane filter (by the dichromate reflux method 508) 3 TS: dried at 103–105°C (2540B) 4 TSS: 2540 D 5 VSS: 2540 E 6 DO: membrane electrode method (4500-0G) 7 SVI: 2710 D 8 Biomass nitrogen content: Kjeldahl method	*System I:* 1 System overload at loads >0.741 kg/m^3 COD/day 2 Treatment efficiencies: >96.8% 3 pH stabilization *System II:* 1 TCOD and SCOD reduction by 50 and 70%, respectively 2 Treatment efficiencies: >98.5% *Both systems:* Minimum organic matter removal: 82% (at loads >1 kg/m^3 COD/day)	Carta-Escobar *et al.*, 2004
B Anaerobic treatment							
2	Wastewater	Treatment with upflow anaerobic sludge blanket (UASB) reactors	pH, COD, VFAs, biogas quantity and quality	Two types of UASB reactors (anaerobic sludge granules from digested cowdung slurry (DCDS) (reactor I) and granules obtained from reactors treating sugar industry wastewaters (reactor II)) were operated at hydraulic retention time (HRT) of 3 and 12 h and on COD loading rates 2.4–13.5 kg/m^3 of digester volume/day	1 pH: pH meters 2 COD: open reflux method (APHA, 1998) 3 VFAs: method of Dilallo and Albertson (1961) 4 Biogas quantity: wet gas flow meters 5 Biogas quality: AIMIL-make gas liquid chromatograph using thermal conductivity detectors	1 3 h HRT: 95.6 and 96.3% maximum COD reduction from the reactor I and II, respectively 2 12 h HRT: 90 and 92% COD reduction in reactor I and II, respectively 3 Both reactors: maximum, second best and the third best COD reduction occurred at loading rates of 10.8, 8.6 and 7.2 kgm^3/day, respectively 4 At loading rates >10.8 kg: reactor's performance dropped 5 Better biodegradation of the waste: the first few months of both reactors	Ramasamy *et al.*, 2004
3	Dairy effluent	Anaerobic treatment	pH, total biogas production, alkalinity, total VFA, individual volatile fatty	A high-rate anaerobic reactor operated for 400 days	1 pH: pH probe 2 Total biogas production: wet-gas flow meter 3 Alkalinity and VFA concentration:	1 90% COD removal at organic loading rate of 10 g COD/m^3/day 2 COD recovery as methane was close to 100% (0.37 l CH$_4$/g COD removed)	Haridas *et al.*, 2005

(*Continued*)

Table 13.4 (*Continued*)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
			acids, TOC, IC, biogas composition, COD, LCFAs		titrimetrically (Anderson and Yang, 1992) 4 Individual volatile fatty acids: gas chromatography 5 TOC and IC: TOC-system 6 Biogas composition: TOC analyzer 7 COD: open reflux method according to Standard Methods (APHA *et al.*, 1995) 8 LCFAs: by GC	3 Scum accumulation and degradation before stable methanation 4 Complete degradation of scum when the reactor was unfed (starvation tests)	
4	Synthetic black water and dairy parlor wastewater	Anaerobic on-site treatment	TCOD, COD_{ss}, COD_{col}, TSS, VSS, TS, VS, N_{tot}, pH, BOD_7 and P_{tot}, methane	The wastes were fed into UASB-septic tanks at low temperatures (10–20°C) for 398 days	1 COD_t: according to Finnish standard methods (SFS 5504, 1988) 2 COD_{ss}: obtained by subtracting paper filtered COD from CODt 3 COD_{col}: by subtracting membrane filtered COD from paper filtered COD 4 TSS, VSS, TS and VS: according to Standard Methods (APHA, 1998) 5 N_{tot}: according to Tecator application note (Perstorp Analytical/Tecator AB, 1995) 6 pH: pH meter 7 BOD_7 and P_{tot}: according to Finnish standard methods (SFS–EN 1899-1, 1998; SFS 3026, 1986, respectively) 8 Methane: GC	1 80% and 90% total chemical oxygen demand (CODt) removal 2 >90% total suspended solids (TSS) removal 3 Dissolved COD (CODdis) and BOD_7 removal was 70% and 93%, respectively 4 Good COD and solids removals in a single-phased reactor for black water and a two-phased system for dairy parlor wastewater 5 High black water nutrient removal, while low dairy parlor nutrient removal	Luostarinen and Rintala, 2005
5	Dairy manure	Anaerobic treatment	TS, VS, VSS, VFAs, ammonia-nitrogen, pH, total coliforms, biogas	Two thermophilic (55°C)–mesophilic (35°C) anaerobic sequencing batch reactor ASBR	1 TS, VS, VSS, VFAs: according to Standard Methods (APHA, 1992) 2 Ammonia-nitrogen:	1 Both HRTs: high solid retention time (SRT) of 13–18 days for all three systems	Dugba and Zhang, 1999

				systems (systems II and III) and one mesophilic (35°C)–mesophilic (35°C) ASBR system were run at two hydraulic retention times (HRTs) (3 and 6 days) and five volatile solids (VS) loading rates (2, 3, 4, 6 and 8 g/l/day)	gas-sensing electrode 3 pH: pH-meter 4 Total coliforms: according to Standard Methods (APHA, 1992) 5 Biogas: by GC	2 HRT of 3 days and VS loading rates of 6 g/l/day: all systems performance was deteriorated 3 HRT of 3 days: ideal VS loading rates were 2–4 g/l/day 4 26.1–44.2% VS removal, 0.2–1.6 l/l/day specific methane production from three systems 5 Biogas: 62–66% CH_4, 28–31% CO_2. A 6 37% NH_3-N concentration increase in treated wastewater 7 Systems with thermophilic reactors: effective in destroying total coliforms	
6	Dairy wastewater	Anaerobic biodegradation	Protein, total sugars, VFA_s, TA, sugar, TSS, VSS, TOC, IC, methane gas	Anaerobic biodegradability batch assays of two types wastewater (COD 0.4–20 g/l) (wastewater A from dissolving full cream milk powder, wastewater B from skimmed milk powder)	1 Protein: by spectrophotometry 2 Sugars: according to method described by Miller (1959) 3 VFA_s: by GC 4 TA: by anion selective electrode 5 Sugar, TSS, VSS: according to Standard Methods (APHA, 1985) 6 TOC, IC: by TOC-analyzer 7 Methane gas: by GC	1 Wastewater A: greater biodegradability and methanization at lower concentrations (1–5 g COD/l) 2 Wastewater A: 98–99% biodegrability at higher concentrations (5–20 g COD/l) 3 Wastewater B: biodegrability decline from 97.5 to 86% 4 Wastewater B: methane production increased linearly with COD increase 5 Wastewater A: methane production increased at low COD (<5 g/l) and inhibited at higher concentrations (>6 g COD/l) 6 Wastewater B: total volatile fatty acids (VFA) accumulation at high COD (5–20 g COD/l), and high free ammonia concentration (60 mg/l) at high COD values (20 g/l)	Vidal *et al.*, 2000
7	Dairy wastewater	Mesophilic anaerobic degradation	VFA, methane, chemical analysis	UASB reactors with different intermittent cycle length 24–144 h and loads 2.5–29.0 g	1 VFA, methane: by GC 2 Chemical analysis: according to Standard Methods (1995)	1 Methane production: higher in the feedless period (22% to 36% of the total methane) compared to the total cycle production	Nadais *et al.*, 2005

(*Continued*)

Table 13.4 (*Continued*)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
				COD/l/day were fed with dairy wastewater (treatments: feed and feedless period)		2 96–98%COD removal ×48 h feed and 48 h feedless period: higher conversion of removed COD to methane raised from 59 to 85%	
8	Mixed liquor (synthetic dairy waste, fresh cow-dung slurry, digested cow-dung slurry)	Anaerobic digestion	TS, VS, COD, pH, biogas	Mixed liquor, which was then replaced with dairy waste, was fed into a continuously-stirred tank reactor (CSTR) by incorporating a biofilm support system (BSS) with HRT of 15 days	1 TS, VS, COD, pH: according to Standard Methods (APHA, 1995) 2 Biogas: by GC	1 Low COD and pH reduction in the effluent 2 Dairy waste (the only feed substrate): biogas yield and pH increased 3 Greater COD reduction in the BSS reactors than in the conventional ones 4 60% volatile solids (VS) decline in the BSS reactors and only 40% in the control (HRT 10 days) 5 56–58% biogas release by both reactors	Ramasamy and Abbasi, 2000
C Membrane treatment							
9	Diluted skimmed milk	Nanofiltration and reverse osmosis	COD, lactose, conductivity, anions and cations	A mixture of water and skimmed milk was filtrated with different membranes in a batch cell (25°C, 1.5 MPa for NF membranes, 2.5 MPa RO membranes, filtration time 8–9 h)	1 COD: test tubes (oxidation with potassium dichromate/sulfuric acid/ silver sulfate at 148°C) and photometric measurement 2 Lactose: spectrophotometrically at 488 nm 3 Cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) concentrations: by atomic absorption 4 Anions (phosphate, citrate, Cl^-) concentrations: ion chromatography 5 Conductivity: conductivity meter	1 COD removal: >99% 2 Lactose removal: 98.2–99.9% 3 Divalent cations removal: >90% 4 Negative rejection of chloride at VRF = 3 using NF membranes 5 Permeate COD levels were significantly higher than the threshold acceptable for human consumption water	Balannec *et al.*, 2005
10	Ovine by-products (ovine cheese whey and	Membrane treatment	Protein, fat, dry matter, ash, chloride, Ca^{2+}, PO_4^{2-}	Ultrafiltration (UF) (*Treatment I*) and thermocalcic precipitation–microfiltration (TP/MF)	1 Protein and fat: infrared spectroscopy 2 Dry matter: oven drying at 105°C for 12 h	1 0.65 mm pore size of MF membranes: more efficient clarification and the obtained product had high protein	Pereira *et al.*, 2002

	deproteinized whey)			using two MF membranes (0.65 and 0.20 mm pore size) followed by UF and diafiltration (UF/DF) (*Treatment II*)	3 Ash: incineration at 550°C for 6 h 4 Protein: Kjeldahl method 5 Fat: gravimetric AOAC procedure (AOAC, 1996a) 6 Chloride: kit 7 Ca^{2+}: atomic absorption spectrometry 8 PO_4^{2-}: colorimetric method of AOAC (1996b)	content and can be used in food industry 2 0.20 mm pore size of MF membranes: poor flux performance and high degree of protein retention	
11	Skimmed milk	Enzymatic hydrolysis	Enzyme activity, glucose, lactose, galactose, glucose concentrations	Skimmed milk was pumped through a hollow fiber module (heat exchanger, manometer, thermometer). At the end of the module, lactose-hydrolyzed product was collected. The enzyme (β-galactosidase) was pumped in a closed circulation, which included a UV irradiation module and a sterile filtration unit	1 Enzyme activity: according to method described by Petzelbauer *et al.* (1999) 2 Glucose: by glucose analyzer 3 Lactose, galactose, glucose concentrations: with HPLC	Lactose conversion decrease from 92.48 to 78.11% (enzyme activity 120 U/ml, 23 ± 2°C, hollow fiber reactor with membrane area of 4.9 m^2)	Novalin *et al.*, 2005
12	Regular and whey buttermilk	Volumetric concentration (VC) and diafiltration (DF)	Total solids, ash, protein, lipids, phospholipids	Use of a ceramic microfiltration (MF) membrane using two different filtration modes, VC and DF, at low temperature (8–10°C) at a transmembrane pressure of 80–95 kPa	1 Total solids: drying in an air oven at 102°C 2 Ash: by incineration at 550°C in a muffle furnace 3 Protein: by macro-Kjeldahl method with 6.38 as a nitrogen to protein conversion factor (Marshall, 1992) 4 Lipids: by Mojonnier ether extraction method (Marshall, 1992) 5 Phospholipids: with HPLC	1 DF process: decrease of protein transmission through the membrane (19.5% regular and 25% whey buttermilk), decrease of ash transmission for regular buttermilk (65.5%), increase in phospholipids transmission for regular buttermilk (39.1%), increase of phospholipids content for regular and whey buttermilk, transmission of lipids for regular and whey buttermilk was 8.5% and 4.7%, respectively 2 VC process: decrease of protein transmission for whey buttermilk (33.0%), total lipids transmission for regular and whey buttermilk	Morin *et al.*, 2006

(*Continued*)

Table 13.4 (*Continued*)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
						was 5.8% and 3%, respectively, whereas in the DF process transmission of lipids for regular and whey buttermilk was higher (8.5% and 4.7%, respectively)	
13	Diluted skimmed milk	Nanofiltration with a rotating disk module	COD, conductivity, pH, dry mass	Diluted skimmed milk fed into a filtration system consisting of a metal disk (smooth or with radial vanes) rotating at high speed near a flat circular membrane operated at a transmembrane pressure (TMP) of 4000 kPa, at 45°C and at rotation speeds of 1000 and 2000 rpm	1 COD: by kits 2 Conductivity: by conductivity meter 3 pH: by pH-meter 4 Dry mass: percentage of total mass after heating the samples at 105°C for 7 h	1 TMP 4000 kPa and 2000 rpm (with vanes): 56.5% permeate flux decrease with increasing volume reduction ratio (VRR) from 1 to 7.5 2 Maximum dry matter percentage (38%): disk with vanes rotating at 2000 rpm 3 Increase of COD and mean ionic concentration with increasing VRR values at 2000 rpm and both types of disks 4 COD was higher at smooth disks than disks with vanes	Frappart *et al.*, 2006
D Constructed wetlands							
14	Dairy parlor wastewater	Treatment with a multiple-phase biological system	–	The system was consisted of an aerated SBR containing activated sludge, followed by a series of constructed wetlands	–	1 SBR: decrease of BOD_5 and COD up to 92.1–96.1% and 86.1–89.5%, respectively 2 Wetlands: reduction of BOD_5 and COD ranging from 70.1 to 81.8% and from 56.6 to 64.5%, respectively 3 Reduction of suspended solids (SS), ammonium, nitrate and phosphorus	Moir *et al.*, 2005
15	Dairy wastewater	Treatment in constructed wetlands	$CBOD_5$, SS, temperature, conductivity, pH, DO, FC, NBOD, dissolved humic color	Planted (*Schoenoplectus validus*) and unplanted gravel-bed wetlands were operated at retention times of 7, 5.5, 3 and 2 days, with in- and outflows sampled	1 $CBOD_5$, SS, temperature, conductivity, pH, DO, FC: according to methods described by APHA (1989) 2 NBOD: 4.33 times the NH4-N concentration (Copper, 1986) 3 Dissolved humic color:	1 $CBOD_5$ removal up to 76–92% and 60–85% in planted and unplanted constructed wetlands, respectively 2 In planted channels BOD ($CBOD_5$ + NBOD) removal decreased from 80 to 50%, whereas in unplanted wetlands	Tanner *et al.*, 1995a

				bimonthly for 20 months	UV spectrophotometer at 440 nm	BOD removal ranged from 60 to 85% 3 75–80% SS and 90–99% FC removal for planted and unplanted wetlands 4 Dissolved humic color was reduced up to 40% at longer retention times	
16	Dairy wastewater	Treatment in constructed wetlands	Ammonium, nitrate and nitrite N, TKN, TP, DRP	Planted (*Schoenoplectus validus*) and unplanted gravel-bed wetlands were operated at retention times of 7, 5.5, 3 and 2 days, with in- and outflows sampled bimonthly for 20 months	1 Ammonium: according to method described by Brown (1973) 2 Nitrate and nitrite N: according to method 418C (APHA, 1985) 3 TKN: modified micro Kjeldahl digestion using selenium catalyst 4 TP and DRP (total and dissolved reactive P): according to method described by NWASCA (1982)	1 TN removal in planted and unplanted channels was 48–75%, and 12–41%, respectively 2 TP removal was 37–74%, and 12–36%, respectively	Tanner *et al.*, 1995b
17	Dairy wastewater	Use of ecological treatment system (ETS)	Ammonium-nitrogen (NH_4-N), nitrite and nitrate, orthophosphate (PO_4-P), CBOD, water quality	The wastewater flowed through the anaerobic reactor, anoxic reactor, closed aerobic reactor, planted aerobic reactor, clarifier, subsurface wetland mesocosm, two more planted aerobic reactors and another clarifier and two more subsurface wetland mesocosms, for 20 weeks	1 Ammonium-nitrogen (NH_4-N): according to method described by Liao (2001) 2 Nitrite and nitrate (NO_x-N): according to method described by Wendt (1995) 3 Orthophosphate (PO_4-P): according to method described by Diamond (1995) 4 CBOD according to 5-day nitrification inhibitor method (Hach *et al.*, 1997) 5 Water quality analyses: using Standard Methods (APHA, 1989)	1 99% removal of ammonium-nitrogen (NH_4-N) and carbonaceous biochemical oxygen demand (CBOD) 2 79% removal of orthophosphate (PO_4-P) 3 Nitrate and nitrite were produced with effluent concentration of 0.53 mg/l and removed within the system	Lansing and Martin, 2006

(*Continued*)

Table 13.4 (*Continued*)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
18	Dairy wastewater	Treatment in a constructed wetland system	Dissolved oxygen, pH, conductivity, temperature, TSS, BOD, total Kjeldahl nitrogen, ammonia, nitrate/nitrite, total phosphorus, ortho-phosphate	The system consisted of two settling basins, two wetland cells planted with *Typha latifolia* L. and *Schoenoplectus tabernaemontani* and a vegetated filter strip colonized by *Lemna minor* L. and *Echinochloa crusgalli*	1 Dissolved oxygen, pH, conductivity, temperature: by portable meters 2 TSS, BOD, total Kjeldahl nitrogen, ammonia, nitrate/nitrite, total phosphorus, ortho-phosphate: according to Standard Methods (APHA, 1992)	1 Reduction of total nitrogen (98%), ammonia (56%), total phosphorus (96%), ortho-phosphate (84%), suspended solids (96%), and BOD (97%) 2 Increase of nitrate/nitrite (82%)	Schaafsma and Baldwin, 1999
E Coagulation/electrocoagulation/flocculation/precipitation							
19	Dairy wastewater	Electro-coagulation	COD, oil-grease	The experiment was conducted in an electrochemical reactor consisting of iron electrodes at 25°C, 0–15 V and 0–3 A	COD and oil-grease: according to Standard Methods for examination of water and wastewater (APHA, 1992)	1 COD and oil-grease removal up to 98% and 99%, respectively 2 The optimum current density, pH and electrolysis time for treating dairy wastewater with COD of 18 300 mg /l and oil-grease of 4570 mg/l were 0.6 mA/cm^2 and 7 and 1min, respectively 3 Energy consumption was 0.003 kWh/kg of COD	Şengil and Özacar, 2006
20	Dairy effluent	Electrochemical oxidation	COD, ammonium nitrogen (NH_4-N), ammonium nitrate (NO_3-N), chloride ion, hypochloride ion, acetic acid	Membrane filters pretreatment of digested effluent obtained from a full-scale anaerobic digester, followed by anodic oxidation and indirect oxidation using dimensionally stable anode (DSA) and lead dioxide coated titanium (Ti/PbO_2) as anode and stainless steel as cathode	1 COD: by dichromate method 2 Ammonium nitrogen (NH_4-N): using salicylate reaction 3 Ammonium nitrate (NO_3-N), chloride ion, hypochloride ion and acetic acid: by capillary electrophoresis (CE) system	1 Higher decreasing rate of NH_4-N at DSA than Ti/PbO_2 anode 2 Higher decreasing rate of COD at Ti/PbO_2 than DSA anode 3 Electrochemical oxidation with DAS: prevention of accumulation of NO_3-N 4 Increase of decreasing rate of NH_4-N with NaCl addition before membrane filtration 5 COD decrease was less effective with NaCl addition before membrane filtration	Ihara *et al.*, 2006
21	Dairy manure effluent	Struvite precipitation	COD, VS, NH_3-N, TP, TDS, pH	The experiment was carried out in stirred batch reactors at room temperature	COD, VS, NH_3-N, TP, TDS, pH: according to Standard Methods (APHA, 1995)	1 Above 95% ammonia (NH_4^+) removal 2 Ammonia removal achieved	Uludag-Demirer *et al.*, 2005

				(21–22 °C) by adding Mg^{2+} in the form of $Mg(OH)_2$ and $MgCl_2 \cdot 6H_2O$		by adding 0.06 M Mg^{2+} in the effluents from one- and two-phase reactors 3 $MgCl_2 \cdot 6H_2O$ was more effective in NH_4^+ removal than $Mg(OH)_2$ 4 Less Mg^{2+} was required in the effluent from two-phase reactor to achieve similar removal efficiencies compared to the effluent from one-phase reactor	
22	Dairy wastewater	Coagulation	Suspended solid, TDS, chloride, sulfate, hardness, FOG, phosphorus, pH, conductivity, turbidity, COD, BOD_5	Coagulation with inorganic (alum and ferric chloride), polymeric (polyaluminium chloride) and naturally organic (sodium carboxymethyl cellulose, alginic acid and chitosan) coagulants, followed by powdered activated charcoal (PAC) treatment *Laboratory-scale experiments:* Ultrafiltration (UF) and reverse osmosis (RO) *Pilot-scale experiments:* Microfiltration (MF) and RO	1 Suspended solid, TDS, chloride, sulfate, hardness, oil and grease content (FOG), and phosphorus: according to Standard Methods (APHA, 1998) 2 pH and conductivity: by pH meter 3 Turbidity: by turbidity-meter 132 4 COD: digestion in a COD reactor, followed by titration with standard ferrous ammonium sulfate 5 BOD_5: by dissolved oxygen meter	1 Optimized conditions: 10 mg/l chitosan, 1.5 g/l dosage of PAC, pH 4.0 2 57% total dissolved solids (TDS), 62% COD reduction, color and odor elimination 3 Laboratory-scale experiments: not significant TDS and COD decrease after UF, 90.8–91.8% TDS and 80–91% COD decrease in RO permeate 4 Pilot scale experiments: 95.8% TDS, 98.5% COD and 95.8% BOD removal of RO permeate	Sarkar *et al.*, 2006
F Bioremediation							
23	Dairy effluent	Polishing by aquatic macrophytes	Physicochemical parameters, total nitrogen (N)	Three aquatic macrophytes (*Eichhornia crassipes*, *Lemna minor* and *Azolla pinnata*) were cultured individually and in combinations and placed in separate aquaria, where each aquarium was filled with dairy effluent	1 Physicochemical analysis: Standard Methods (1995) 2 Total nitrogen (N): by micro-Kjeldahl method	1 Nitrogen (N) removal by *E. crassipes*, *Lemna minor* and *Azolla pinnata* was 71.8%, 62.5% and 60.1%, respectively 2 Phosphorus (P) removal by *E. crassipes*, *Lemna minor* and *Azolla pinnata* was 63.2%, 58.8% and 56.3%, respectively 3 The highest removal of N (78.8%) and P (69.4%) was reported in mixed culture of *E. crassipes* and *L. minor*	Tripathi and Upadhyay, 2003
24	Dairy manure	Fermentation	DM, NDF, ADF, ADL, total carbon,	Inoculation with pure culture of either 10% (v/v)	1 DM: by drying at 105 °C	1 Production of cellulase with high level of β-glucosidase at	Wen *et al.*, 2005

(*Continued*)

Table 13.4 (*Continued*)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
			total nitrogen ammonium, potassium, phosphorus, calcium, magnesium, sodium, sulfur, iron, manganese, zinc, cobalt, copper, glucose concentrations, total cellulose, β-glucosidase	*T. reesei* (25.5°C and pH 5.76) or 10% (v/v) *A. phoenicis* (28.2°C and pH 5.14) or mixed culture 10% (v/v) *T. reesei* and 10% (v/v) *A. phoenicis* (27°C, pH 5.5)	2 NDF, ADF, ADL: by gravimetric method (Goering and van Soest, 1970) 3 Total carbon and total nitrogen: using automatic combustion 4 Ammonium: by titrimetric method (Eaton *et al.*, 1995) 5 Potassium, phosphorus, calcium, magnesium, sodium, sulfur, iron, manganese, zinc, cobalt, copper: EPA method 3050/6010 6 Glucose concentrations: using an enzyme assay kit 7 Total cellulose and β-glucosidase activities: according to standard IUPAC procedures	mixed culture of *T. reesei* and *A. phoenicis* 2 β-glucosidase and filter paper activity were 0.6 IU/ml and 1.5 FPU/ml, respectively 3 Higher β-glucosidase production than commercial enzyme and commercial enzyme broth of the pure culture of *T. reesei*	
25	Sugarcane trash and cattle dung	Composting	Organic C, total N, water-soluble C, total C, cellulose, xylanase, protease activities, CO_2, changes in microflora, humic substances	A mixture of sugarcane trash and cattle dung (4:1 or 1:1 dry weight) was composted for 14, 30, 45, 60 and 90 days (moisture 60% of water-holding capacity (WHC), 28–30–45°C)	1 Organic C: dry combustion (Nelson and Sommers, 1982) 2 Total N: Kjeldahl method (Bremner and Mulvaney, 1982) 3 Water soluble C: in water extract oven dried and sieved compost was suspended in distilled and shaken for 30 min and filtered 4 Total C: titrimetric method (Kalembasa and Jenkinson, 1973) 5 Cellulase and xylanase activities: by the method of Schinner and Von Mersi (1990) 6 Protease activity: by measuring hydrolysis of	1 Organic carbon and C/N ratio decreased with time 2 Total nitrogen increased with time 3 Maximum enzyme activities for cellulase, xylanase and protease were reported after 30 and 60 days of composting 4 Population of thermophilic and mesophilic bacteria had the highest value at 14 and 30 days of composting, respectively and declined with time 5 Mesophilic population had the highest value at 30 days of composting and decreased with time 6 Thermophilic population reduced during composting	Goyal *et al.*, 2005

					casein by method of Ladd and Butler (1972) 7 CO_2: by trapping the CO_2 in NaOH solution and titrating it with HCl after addition of saturated barium chloride (Garcia *et al.*, 1992) 8 Changes in the microflora: plating on nutrient agar and Martin's rose begal medium and incubation at 30°C and 45°C for mesophilic and thermophilic microorganisms, respectively 9 Humic substances: according to method of Kononova (1961)		
26	Dairy wastewater	Fermentation	CO_2, biomass, OUR, specific oxygen uptake, SVI, microorganism colony morphology	*Batch mode experiments:* Dairy wastewater (COD 0.5–4 g/l) fed into bioreactor at pH 7, 30°C, 200 rpm *Continuous mode experiments:* Industrial effluent or model effluent consisting of homogenized whole milk (COD 0.5–1.9 g/l) fed into bioreactor at 19–23°C	1 CO_2: with GC 2 Biomass: with gravimetric method 3 Oxygen uptake rate (OUR): by measuring dissolved oxygen versus time 4 Specific oxygen uptake: calculating the ratio between OUR and VSS 5 SVI: calculating the ratio between sludge volume and VSS 6 Microorganism colony morphology: after 24–48 h of cultivation at 37°C and by BOX-PCR genomic fingerprinting	1 Batch tests: 78% COD removal, CO_2 production 1.1 g per g of COD removed and biomass yield 0.41 g volatile suspended solids (VSS)/g of COD removed 2 Continuous tests: 89% COD removal	Loperena *et al.*, 2006
27	Municipal solid wastes	Composting	Cumulative mass of carbon dioxide, dissolved ammonia	Composting in an aerobic digester operated at 52 ± 2°C (thermophilic temperature) for 47–198 days. Addition of partially composted municipal waste to some runs	1 Cumulative mass of carbon dioxide: by titration 2 Dissolved ammonia: by distillation/titration	1 CO_2 emission after addition of partially composted municipal waste to paper or yard or food waste (composted individually): 150–370 g CO_2-C and 2.0–34 g NH_3-N per dry kg of starting material	Komilis and Ham, 2006

(*Continued*)

Table 13.4 (*Continued*)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
						2 CO_2 emission of all mixtures: 240–300 g CO_2-C per dry kg of initial substrate, NH_3 production was 0.5–15 g NH_3-N per dry kg of initial substrate	
28	Cheese whey	Bioremediation (two strategies)	Organic acids, sugar, ethanol, COD, protein, analysis of exit gas from the bioreactor	*First strategy:* Anaerobic, mesophilic (45°C) first stage, followed by an aerobic, mesophilic (45°C) second stage *Second strategy:* Anaerobic, mesophilic (45°C) first stage, followed by an aerobic, thermophilic (55–65°C) second stage	1 Organic acids, sugar, ethanol: with HPLC 2 COD: with reactor digestion method (Jirka and Carter, 1975) 3 Protein: using a Coomassie protein assay reagent based on the Brandford method 4 Analysis of exit gas from the bioreactor: by mass spectrometer	1 Dissolved oxygen (DO): >80% of saturation during aerobic processing, whereas DO >65% of saturation during the thermophilic stage 2 68% COD decrease during the anaerobic and aerobic stages and 59% soluble protein decline 3 Thermophilic treatment: 62.5% COD and 47.5% soluble protein decline 4 Second strategy: 100% reduction of COD and lactose and 90% decrease in soluble protein	Kosseva *et al.*, 2003
G Miscellaneous treatment methods							
29	Dairy manure (fibers)	Acid hydrolysis	NDF, ADF, ADL, ash, mono-sugars, metal elements (calcium, magnesium, sodium and potassium), phosphorus, nitrogen, crude protein, carbon, sulfur, nitrogen, structure changes	Diluted dairy manure to different acid concentrations (65%, 70% and 75%) was used for acid hydrolysis experiments at 100°C for 1 h at four treatment durations (30, 60, 90 and 120 min). Decrystallized manure was subject to acid hydrolysis under two acid concentrations (10% and 12.5%), three levels of temperatures (100, 120 and 135°C) and six reaction times (10, 20, 30, 60, 90, 120, 150, and 180 min)	1 NDF, ADF, ADL and ash: by using Van Soest Fiber Analysis System (Goering and van Soest, 1970) 2 Hemi-cellulose: by the difference of %NDF − %ADF 3 Mono-sugars: with ion chromatograph 4 Metal elements (calcium, magnesium, sodium and potassium): by using atomic absorption 5 Phosphorus, nitrogen and crude protein: by using AOAC method (Association of Official Analytical Chemists, 1990) 6 Carbon, sulfur and nitrogen: by automated combustion	1 Optimal conditions for decrystallization: 75% acid concentration, 3:5 sample to acid ratio (weight basis), and 30 min reaction time 2 Optimal conditions for acid hydrolysis: 12.5% acid and 10% dry sample at 135°C for 10 min 3 Under optimal conditions: 84% glucose (26 g/l) and 80% hemicellulose-sugars (11 g/l) production	Liao *et al.*, 2006

					techniques 7 Structure changes: by using a scanning electron microscope		
30	Dairy manure	Two-phase anaerobic digestion	COD, VS, NH_3-N, TKN, TP, pH	Dairy manure was fed into an acidifying reactor for 26 days (SRT/HRT 10 days, organic loading rate (OLR) 1.19 g COD/l day (1.0 g VS/l day)). The effluent was then fed into a methanogenic reactor for 21 days (same OLR, influent VS concentration 0.91%). For 86 days the two-phase reactor was operated at SRT/HRT of 10 days, at different OLR (2.39–15.06 g COD/l day or 2.0–12.6 g VS/l day, respectively) and influent VS concentrations (1.83–11.5%)	COD, VS, NH_3-N, TKN, TP, and pH: according to Standard Methods (APHA, 1995)	1 Highest biogas production rate: 2.272 l/day at OLR of 7.53 g COD/l day 2 Highest biogas yield: 1.76–1.78 l biogas/g VS added at OLR of 5.97 and 7.53 g COD/l day 3 Biogas production: 50% and 67% higher at ORL of 5.97 and 7.53 g COD/l day, respectively, compared to one-phase reactor (SRT/HRT of 20 days) 4 Two-phase reactor: 30–71% COD and 16–70% VS removal 5 One-phase reactor: 45–77% COD and 36–70% VS decrease (SRT/HRT of 20 days) and 24–50% COD and 16–40% VS decline (at SRT/HRT of 10 days)	Demirer and Chen, 2005
31	Dairy manure	Fixed-film anaerobic digestion	TS, VS, FS, TCOD, pH, alkalinity, EC	Flushed dairy was flowed down to a sand-trap and to a mechanical separator for large fibrous solids removal. The separated wastewater was directed to a sedimentation basin and then into a sampling pit and a storage pond. Pretreated wastewater was pumped to an anaerobic lagoon, where the liquid was irrigated onto cropland	TS, VS, FS, COD-T, pH, alkalinity, and EC: according to Standard Methods (APHA, 1995)	1 Screening and sedimentation: 46.7% total solids (TS), 60.4% volatile solids (VS) and 42.2% total COD removal 2 Higher flushed dairy manure temperatures reduced TS, VS, and total COD removal efficiencies	Wilkie *et al.*, 2004
32	Dairy effluent	Lactose adsorption	Lactose	Adsorption was studied at 30°C using aqueous concentrations from 200 to 1000 mg/l	Lactose: by total organic carbon measurement equipment	Very small amount of lactose was adsorbed by the organophilic clay (0.3–0.5%)	Morais *et al.*, 2005

Biogas/methane/hydrogen production

Biogas production from agricultural biomass is of growing importance because it offers considerable environmental benefits and an additional source of income for farmers (Chynoweth, 2004). However, hydrogen is now considered as one of the alternatives to fossil fuels. It is preferred to biogas or methane because hydrogen is not chemically bound to carbon and, therefore, burning does not contribute to the greenhouse effect or acid rain (Nath and Das, 2004).

Biogas production from farm dairy wastewater treated in an anaerobic waste stabilization pond was developed and applied to an anaerobic pond treating farm dairy waste by McGrath and Mason (2004). The dairy wastewater was fed to a pond, part of a two-stage anaerobic/facultative waste stabilization pond system, and the loading rates were of 0.12 kg (BOD_5)/cow/day and 0.38 kg (VS)/cow/day, the operation time 190 days and the temperature varied between 13 and 15°C for the first 60 days and reached the maximum value of 24°C at day 190. Biogas detection was reported between 137 and 190 days, while the highest biogas volume was reported at day 138 and was 112 l. Total biogas production varied from 0.002 to 0.039 m^3/m^2/day.

The potential of biogas production from maize and dairy cattle manure was investigated by Amon and coworkers (2006). Dairy manure obtained from cattle with various milk yields and feeding intensities and different ripening varieties of maize (*Zea mays* L.) (early, medium, late) were fed into anaerobic batch digesters at 38°C for 60 days. Biogas and methane yield from dairy manure was 208.2–267.7 Nl/kg VS and 125.5–166.3 Nl CH_4/kg VS, respectively. The maximum methane yield was recorded after anaerobic digestion of whole maize crops, whereas 43–70% less methane per hectare was recovered from digestion of corn cob mix, only corns or maize. In early and medium ripening varieties, methane yield was 5300–8500 Nm^3 CH_4/ha, while in late ripening varieties yielded 7100–9000 Nm^3 CH_4/ha.

A gasification system, known as MEET (multistaged enthalpy extraction technology), uses high temperature and preheated air as the gasification medium and was fed with dairy cow manure. A flammable raw synthetic gas (syngas) consisting of CO, H_2 and N_2 was produced and inorganic ash residue was extracted either as a molten slag (slagging mode of operation) or as ash (non-slagging or dry-bottom operation), depending on the selected operating temperature of the gasifier. In slagging mode of operation, the temperature ranged from 1350 to 1400°C, while in the non-slagging operation, the temperature was maintained between 800 and 900°C. The results indicated gasification conversion efficiencies of 65–85%, depending on operation mode and syngas utilization for electricity and heat generation, or for other energy needs, thus reducing the operating costs of the farm (Young and Pian, 2003).

Callaghan *et al.* (1999) evaluated the co-digestion of cattle slurries with various solid wastes, such as chicken manure (TS content 7.5% and 15%), food and vegetable waste (TS 9.2%), fish offal (TS 8.7%), dissolved air flotation sludge and brewery sludge. Cattle slurries and solid wastes were placed in batch digesters and mixed at 120 rpm and 35°C. In general, volatile solids (VS) reductions were between 45 and 55%, even though the highest VS removal was 81% and was observed during co-digestion of cattle slurry with chicken manure (TS content 15%). Cumulative

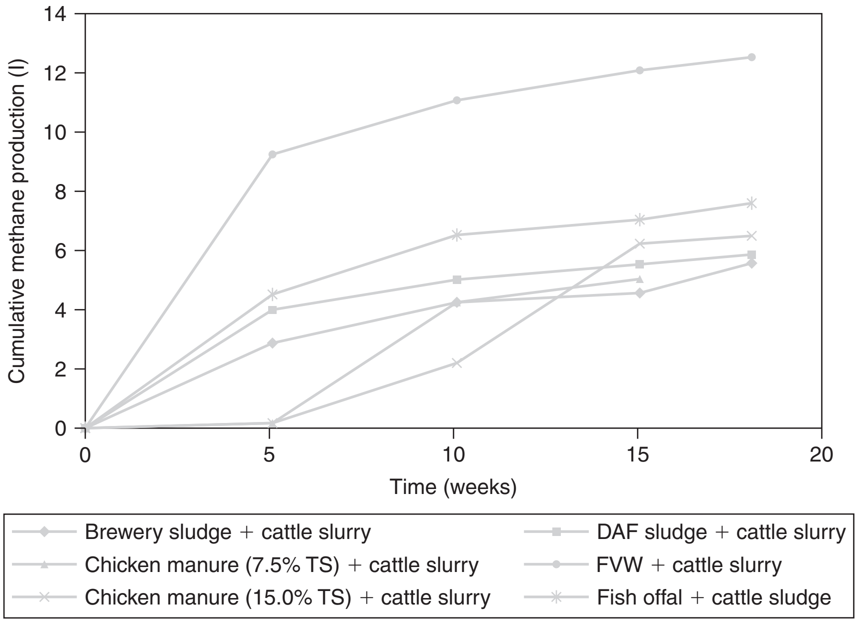

Figure 13.12 Mean cumulative methane production of cattle slurries with various solid wastes (adapted from Callaghan *et al.*, 1999)

methane production of co-digestions with fruit and vegetable waste was the highest of all the other co-digestions (Figure 13.12). The highest specific gas yield was reported in co-digestions of cattle manure and fish offal or brewery sludge (0.38 and 0.31 m^3 CH_4/kg VS removed, respectively), whereas the lowest values were recorded in co-digestion of cattle manure with food and vegetable waste or chicken manure (0.13–1.16 m^3 CH_4/kg VS removed). Finally, an increase in N concentration was observed, with the greatest increase reported in digesters fed with chicken manure.

Dairy manure with total solids (TS) concentration 7–8% was screened and then subject to coagulation/flocculation, using calcium oxide (CaO) as coagulant and a cationic polyacrylamide as flocculant, obtaining liquid and solid fractions. The solid fractions contained 75.2% of the initial manure TS, 80.4% of the volatile solids (VS), 58.6% of the total Kjeldahl nitrogen (TKN) and 87.4% of the total phosphorus (TP). On the contrary, the liquid fraction contained 21.8% of the initial manure TS, 17.0% of the VS, 39.5% of the TKN and 10.8% of the TP. For the liquid fraction, the mean percentage of COD that was metabolized by anaerobic microorganisms was 83.7%. The specific methane production for the dairy manure, the screened manure and the liquid fraction were 0.307, 0.371, and 0.6041 NCTP CH_4/g VS, respectively (Table 13.5) (Rico *et al.*, 2007).

Ferchichi *et al.* (2005) studied the influence of initial pH on hydrogen (H_2) production from fresh crude (unskimmed) cheese whey by *Clostridium saccharoperbutylacetonicum*. The fermentation process was carried out in a pH range from 5 to 10, at 30°C and at agitation speed 50 rpm. Sugar consumption remained high at 97% at

Table 13.5 Specific methanogenic production (at 35°C) of dairy manure, screened manure and liquid fraction

Days	Specific methanogenic production (l NCTP CH_4/g VS)		
	Dairy manure	Screened manure	Liquid fraction
0	0	0	0
10	0.180	0.250	0.600
20	0.280	0.350	0.600
30	0.300	0.371	0.604
40	0.307	0.371	0.604

Adapted from Rico *et al.*, 2006

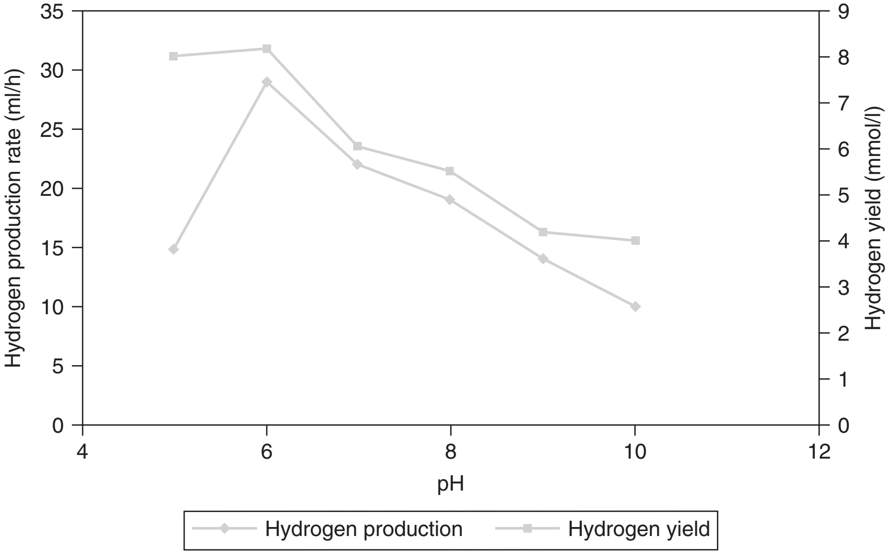

Figure 13.13 Relationship between pH and hydrogen production rate and yield (adapted from Ferchichi *et al.*, 2005)

pH 5–9 and decreased down to 92% at pH 10. The results showed that H_2 production was pH-dependent, while the same trend was observed in H_2 production rate and yield. The highest H_2 production (1432 ml), yield (7.89 mmol/g lactose) and the maximum production rate (47.07 ml/h) were observed at pH 6 (Figure 13.13). The final pH of the culture ranged from 5.5 to 6.1 and increased with initial pH, while shorter fermentation times (50–52 h) were reported at pH 6–8, but outside this range, fermentation times were much longer (62–80 h).

Fertilizer

Composting is a widely used method for disposal of organic wastes. Application of un-composted wastes or non-stabilized compost to land may lead to immobilization of plant nutrients and cause phytotoxicity (Butler *et al.*, 2001; Fuchs, 2002; Cambardella *et al.*, 2003). Composting converts manure and bedding nutrients into a more stable form, adds humic acid to the soil, increases beneficial soil organisms, improves soil tilth and aeration, reduces raw manure odors and reduces reliance on synthetic fertilizers. Various methods are available to produce compost (http://cru.cahe.wsu.edu/CEPublications/eb1947b/eb1947b.pdf). The use of organic manures as amendments to improve soil organic matter level and long-term soil fertility and productivity is gaining importance. The benefits of composted organic wastes to soil structure, fertility, as well as plant growth, have been increasingly emphasized (Chen *et al.*, 1992; Murwira *et al.*, 1995; Esse *et al.*, 2001). Therefore, composting processes have the potential to reduce significantly environmental problems associated with manure management (Carr *et al.*, 1995).

Bol and coworkers (2003) examined the short-term effects of land application of dairy slurry amendment on carbon sequestration and enzyme activities in temperate grassland. Slurry collected from cows fed with either ryegrass (*Lolium perenne* – C3 plant) or maize (*Zea mays* L – C4 plant) silages was applied to soil. The results showed that water-soluble organic carbon (WSOC) content was two to three times higher in the amended soil in comparison to non-amended soil, whereas no significant change in the soil microbial biomass (SMB) carbon content was recorded 4 weeks after the application of slurry. Furthermore, higher urease, cellobiohydrolase, β-N-acetyl-glucosamidase, β-glucosidase and acid phosphatase activities in slurry treated soil were observed.

Fish bioassays on an economically important and widely cultured fish, rohu (*Labeo rohita*), for the evaluation of raw and bioremediated dairy effluent were conducted by Mishra *et al.* (2000). Dairy effluent (0%, 50%, 60%, 70%, 80%, 90% and 100% concentrations) was treated with *Wollfia arrhiza* (pteridophyte) and, after 15 days of bioremediation, the *Wollfia* was removed and the collected effluent was utilized for bioassay at the same concentrations as the raw dairy effluent. Bioassays were performed by exposing test animals to 10%, 20%, 30%, 40%, 50% and 60% concentrations of diluted raw dairy effluent (Figure 13.14). After 96 h of exposure 0%, 30%, 60%, 90%, 100% mortalities were recorded in that order. There were reductions up to 74% in BOD, 72% in COD, 58% in total available nitrogen (TAN) (NH_4^+-N, NO_2^--N, NO_3^--N), and 76% in available phosphorus (TP) (PO_4^{2-}-P) (Figure 13.15). Furthermore, the 96-h LC50 values of raw and treated dairy effluent on *Labeo rohita* were 25.5% and 73.5%, respectively. Bioremediated dairy effluent can be used in aquaculture as a fertilizer with proper dilution.

Straw, two green waste composts (GWC1, GWC2), sawdust, paper sludge and tannic acid were mixed with celery leaves (*Apium graveolens* L.) for nitrogen (N) immobilization from crop residues, while malting sludge, vinasses, molasses and dairy sludge were added to the treatments for immobilized N remineralization. The fastest N immobilization was observed with straw (30.2 mg N/kg), whereas the slowest with tannic acid, sawdust and GWC1 (16.4, 15.9 and 8.0 mg N/kg, respectively). No N immobilization was reported with paper sludge and GWC2. On the other hand, N remineralization was recorded only with a mixture of GWC1 and vinasses (55.4 mg N/kg). Therefore, organic biological wastes (OBW) can be used for nitrate concentration reduction in soil due to the N-release from vegetable crop residues (Chaves *et al.*, 2005).

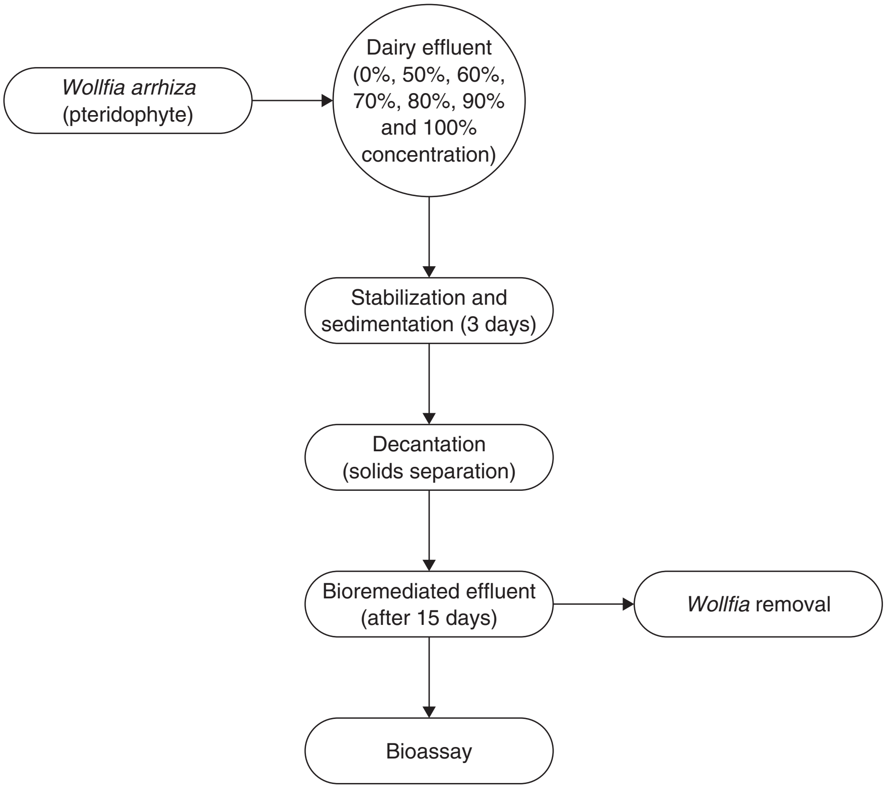

Figure 13.14 Bioremediation of dairy slurry for fish bioassays (adapted from Mishra *et al.*, 2000)

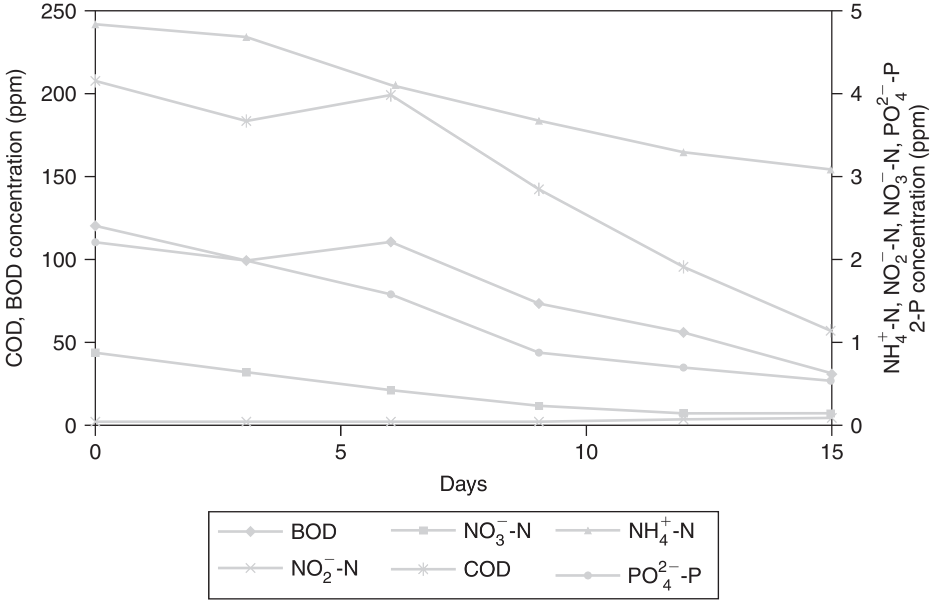

Figure 13.15 Changes in physicochemical parameters of raw undiluted dairy effluent during bioremediation (adapted from Mishra *et al.*, 2000)

The thermophilic aeration of cattle slurry and food industrial by-products was examined by Heinonen-Tanski *et al.* (2005). Cattle slurry alone and a mixture of cattle slurry, whey and/or jam wastes (slurry:whey:jam 45%:27.5%:27.5%; slurry:(whey or jam) 70%:30%) were aerated in a heat-insulated reactor with retention times of 4–5 days. The process started in winter when the ambient temperature ranged from 0 to −21°C and ended in summer at 20°C. The heat energy formed was higher than the electrical energy needed to carry out the aeration, thus indicating that the extra heat could be utilized for preheating the water, which is needed in a farm household and for washing of milking products and the final product could be used as a fertilizer and soil improving compound to increase the organic matter content of soil. Whey waste suited better for co-composting than jam waste but the mixture of whey, jam waste and slurry was optimal for composting.

Sarathchandra *et al.* (2006) examined the potential effects of high carbon dairy factory effluent application on the growth of perennial ryegrass (*Lolium perenne* L.) and soil microorganisms. Ryegrass seedlings were planted in pots and kept in a controlled-environment room at 20°C, with 16 h light/8 h dark. Dairy effluent was added to the pots at three different rates. Shoot samples were harvested from each treatment at 32, 61 and 130 days after the initial effluent addition. After 32 days, dry matter content declined remarkably with increasing effluent rate, whereas at 130 days effluent treated pots had greater shoot dry matter with increasing effluent rate. A decrease in nitrogen and sulfur concentration in shoots was observed in treated pots, in comparison with phosphorus concentration that was greater in treated than untreated pots. Effluent application increased the populations of potentially pathogenic fungi in roots and decreased the diversity and species richness of total fungi. Root pathogens, such as *Fusarium oxysporum*, total *Fusarium* spp. and *Pythium* spp. increased in treated pots, even though after 130 days *Codinaea fertilis* population decreased significantly with effluent treatment.

The potential of utilization of anaerobically digested dairy slurry combined with other wastes was investigated by Tani *et al.* (2006). Grass growth experiments in the field were conducted by applying digested slurry mixed with 1% or 4% (w/w) ground dry chemical extinguishing agents to orchard grass. Furthermore, plant growth experiments in pots were performed by adding raw and digested slurry mixed with 0%, 0.25%, 0.5% and 0.75% finely ground animal bone ash to dent corn. Dry matter yield of orchard grass was largest to plots with 4% chemical extinguishing agents, followed by control plots (only chemical fertilizers, such as ammonium sulfate, super-phosphate and potassium sulfate were applied), plots with 1% chemical agents and plots with original slurry. On the other hand, dry matter yield of dent corn increased with increase in amount of bone ash added to both raw and digested slurry, even though the yield was significantly higher in the digested than the raw slurry plot. Therefore, digested dairy cattle slurry combined with other wastes were converted to unique soil resources and used for application to agricultural land.

Entry and coworkers (2005) investigated the effect of solid dairy manure and compost with and without alum ($Al_2(SO_4)_3$) on the survival of indicator bacteria (*Escherichia coli*, *Enterococcus* spp. and fecal coliforms) in 0–10 cm soil depth and on fresh potato skins 1, 7, 14, 28, 179 and 297 days after application. The application of solid dairy compost or manure to soil did not increase *E. coli*, *Enterococcus* spp. and fecal coliform populations on any day sampled. The addition of solid dairy manure to soil increased *Enterococcus* spp. and fecal coliform populations in potato rhizospheres. However, fresh potato skins had higher *Enterococcus* spp. and fecal coliform numbers when the solid dairy manure was added to soil in comparison with dairy compost, N-P inorganic fertilizer and N fertilizer. After 7, 14, 28, 179 and 297 days of solid dairy waste and compost and alum application, alum did not affect *Enterococcus* spp. and fecal coliform numbers in the soil. *E. coli* was not detected in any soil, fresh potato skin or potato wash water after dairy manure or compost application regardless of alum treatment on any sampling day.

Dairy manure blended with wheat straw or sawdust (mostly *Quercus* spp.) was composted in windrows at 55–70°C for 4 months. The obtained compost was mixed with peat at different proportions (0, 5, 10, 15, 30, 40, 50 and 100% (v/v)) and used as a substrate for cucumber (*Cucumis sativus* L.) seedling emergence and growth. The greatest differences in the dry weight of shoots were reported in mixtures of 70% peat and 30% compost. Dairy manure-wheat straw compost sampled 0, 14 and 28 days inhibited cucumber growth. Shoot dry weight increased when older (dairy manure-wheat straw or dairy manure-sawdust) composts were mixed with peat. Shoot nitrogen (N) concentration increased from 2.4% in fresh dairy-straw compost mix to 4.0% after 3 months of composting. In dairy manure-wheat straw treatments the concentration of all the other nutrients was within the recommended sufficiency range, whereas the calcium concentration was significantly low (0.6–0.8%). On the other hand, in dairy manure-sawdust treatments the concentration of all nutrients was within the recommended sufficiency range, while N concentration remained low (1.5–2.0%) even in mature composts, Ca concentration was significantly low (0.6–0.7%) and Mo concentration reached the sufficiency range (0.4–1.0%) after 84 days of composting (Wang *et al.*, 2004).

Feces and urine of dairy cows with bedding material and straw were composted in windrow piles for 2 months under controlled aeration and moisture conditions. The four treatments examined were as follows: no turning/no watering, no turning/watering, turning/no watering and turning/watering. Compost samples after 1 month (immature compost) and 2 months (mature compost) of composting initiation, were mixed with soil at two different rates, 1.1 g (low rate) or 3.3 g (high rate) composts (dry weight) per 100 g soil, and placed in an incubator at 20 ± 2°C for 84 days. An increase in inorganic NO_3^--N accumulation in soils amended with mature compost obtained from all treatments was reported, while soil mineralization was higher at high rates of composts which were turned during composting. Furthermore, inorganic N accumulation did not differ significantly among soils mixed with immature compost obtained from the four treatments. Compost can be used as an N-fertilizer after intensive aeration and moisture management (turning and watering) during composting (Shi *et al.*, 1999).

Dairy manure effluent treatment by algal turf scrubber technology was performed by Pizarro *et al.* (2006). Raw manure from a 1000-cow dairy was mechanically scraped (or flushed with water) and the resultant manure slurry was subjected to solids separation before manure solids composting and treatment of the manure effluent by anaerobic digestion and algal scrubbing. Dried algal biomass was rich in nutrients, which were concentrated and stabilized, pathogens were eliminated, heavy metal content was below regulatory limits and easily ground for different formulations. The obtained compost was applied to land, whereas the biomass from the algal scrubbers was either used as a feed supplement or organic fertilizer or exported from the farm. The recovered organic fertilizer was equivalent to a commercial organic fertilizer as far as plant mass and nutrient content was concerned. Finally, the total energy produced from a dairy farm with 1000 cows during anaerobic digestion was 10 700 Mcal/day or 3.9×10^6 Mcal/year, and could be utilized for biomass drying, pumping water and repayment of capital investment.

Animal feedstuff

The food processing industry performs reasonably well at finding value in by-product streams, most often as animal feeds, so it is expected that real 'losses' in food processing will be relatively small (Heller and Keoleian, 2003).

The effect of radiation processing on cow manure as an integral part of the safe recycling was determined by Dia El-Din *et al.* (1999). Air-dried cow manure was treated with gamma irradiation at dose rates of 5, 10 and 25 kGy. Short-term feeding experiments were carried out to determine the effect of radiation of cow waste on growth performance of young chicks. Broiler chicks were fed for 6 weeks with control diet, non-irradiated and irradiated manure at 10 and 25 kGy. The thiamine (vitamin B1) content of the irradiated samples was not significantly different from non-irradiated samples. Irradiated manure with 25 kGy gamma rays displayed an increase in concentration of some amino acids (i.e. arginine, threonine, alanine, tyrosine, valine, methionine, etc.) and a decrease in other amino acids (glutamic acid, serine, glucine, histine). Furthermore, the body gain of chicks fed with non-irradiated and irradiated manure at 10 and 25 kGy was less than control diet by 11.8%, 6.8% and 5.6%, respectively. The mean body weight of chicks fed with untreated and irradiated manure at 10 and 25 kGy was less than those fed with control diet by 10.9%, 6.4%, and 5.2%, respectively.

Scerra and colleagues (1999) investigated the potential of growing different strains of *Penicillium* spp. from dairy products on bergamot fruit peel in solid state. Three strains of *P. camemberti* and seven strains of *P. roqueforti*, obtained from commercial samples of cheeses, were inoculated into Petri dishes and incubated at 25°C for 5 days. Spores of each strain of *Penicillium* were inoculated in bergamot fruit peel pieces and incubated at 25°C for 10 days. A significant increase in crude protein, ether extract, gross energy and structural carbohydrates (neutral detergent fiber, acid detergent fiber, hemicellulose, cellulose) was reported. Therefore, citrus fruit peel can be used as an animal feed, due to increased nutritional value by single cell protein.

Vasala *et al.* (2005) looked into the potential of lactic acid production from high salt containing dairy by-products by *Lactobacillus salivarius* ssp. *salicinius* with pretreatment by proteolytic microorganisms. Four proteolytic microorganisms (*Acinetobacter* spp., *Bacillus megaterium*, *Pseudomonas fluorescens* and *Flavobacterium balustinum*) were added to cheese whey (with 3 g/l whey protein content) and lactose mother liquor

(90 g/l lactose, 9 g/l proteins, 30 g/l other solids) and cultivated aerobically at pH 6.0 and 30°C for 40 h. Lactic acid bacteria cultures (*Lactobacillus casei*, *Lactobacillus rhamnosus*, *Lactobacillus pentosus*, *Lactobacillus salivarius* ssp. *salicinius*, *Lactobacillus salivarius* ssp. *salivarius*) were then added to dairy by-products and cultivated at 37°C. Moreover, another fermentation experiment was carried out in batch bioreactors by adding proteolytic enzymes (alcalase and flavorenzyme) instead of inoculating proteolytic microorganisms into dairy by-products at pH >5.5, 30°C for *L. casei* and 40°C for the other strains. *Lactobacillus salivarius* ssp. *salicinius* proved to be the ideal microorganism for fermentation of high salt and lactose by-products from the dairy industry. Moreover, processed dairy waste can be utilized as an animal feed, due to its advantage of being a probiotic organism. Complete conversion of lactose to lactic acid was reported in the presence of proteolytic microorganisms, while the most rapid acid production was recorded with the addition of protease enzymes.

Food industry

The food processing industry has its own demands concerning the safety of foodstuffs it receives from primary production. Production on farms should be the first target of countermeasures for the safety of food. Farms and industry require reliable information on the contamination level in milk, based on measurements, in order to decide whether milk should be used in dairy production or be disposed of as waste (Rantavaara *et al.*, 2005).

The extraction of milk-clotting enzymes from fish stomach mucosa for cheese manufacture would provide an inexpensive alternative to rennet substitutes for domestic use or to export to cheese-producing nations and would become a new food-related industry. Tavares *et al.* (1997) isolated tuna fish gastric proteases using 25% NaCl solution (w/v) at different holding times (0–3 h), prior to the enzyme activation at pH 5.0, that can be used as an alternative to rennet substitutes. However, further studies are required for testing tuna protease as rennet substitute on an industrial scale.

Milk or whey from dairy industry waste was concentrated with vacuum evaporator at 20°C. Raw lactose was obtained on filter-centrifuge or vacuum filter from whey concentrate (45–65% dry weight) and processed by pre-crystallization and purified into lactose. Lactose remaining in the filtrate was purified from whey proteins by ultrafiltration (UF) and diafiltration (DF) (transmembrane pressure of 0.1 MPa, permeate flow rate of 10 ml/min). Permeate can be further separated from monovalent salts with nanofiltration (NF) to obtain minerals and vitamins. Whey concentrates or whey protein concentrates can be utilized both for sweet and salt foodstuffs (emulsions with 30–50% vegetable oil), extraction of vegetables and fruits, instant flours and additives for soups. On the other hand, lactose, minerals and vitamins can be effectively used in dietetic foodstuff for diabetics and hypertensic patients (Ostojic *et al.*, 2005).

Nanofiltration of cottage cheese whey for the recovery of by-products was performed by Nguyen *et al.* (2003). Cottage cheese whey samples were decanted, heated (65°C), filtered through a cheese bag, heated again (65°C, 60 min) for pasteurization

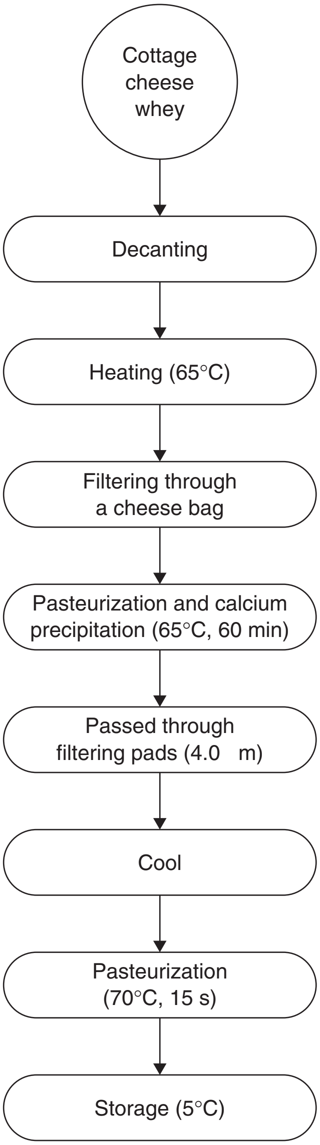

Figure 13.16 Nanofiltration process of cottage cheese whey for recovery of by-products (adapted from Nguyen *et al.*, 2003)

and calcium precipitation, passed through filtering pads (4.0 μm), cooled and were pasteurized (75°C, 15 s) before storage (5°C) (Figure 13.16). An increase in total solids (TS) up to 17.8% and a decrease in sodium concentrate up to 16.3% in the concentrate were recorded. The final concentrate contained significant amounts of fat (1.2%), protein (2.4%) and lactose (19.7%), thus indicating that it can be used in dairy products such as ice-cream and yogurt and can be converted into sweet syrup for use in other products.

Miscellaneous uses

Frozen paste from filleting waste of silver carp (*Hypophthalmichthys molitrix*) was mixed with microbial transglutaminase (3 g/kg), dairy proteins, such as whey protein and sodium caseinate (10 g/kg) and NaCl (0, 10, 20 g/kg) for 2 min at 15°C. The sample was sprayed with commercial regular vegetable oil and immersed in water at 40°C for 1 h and afterwards at 90°C for 20 min. Then, the mixture was placed in a water bath and cooled at 4–5°C for 30 min. Restructured fish products with different levels of salt (0, 1 and 2%) were obtained. The mechanical properties of fish gels increased when the salt level of the samples containing or not dairy proteins increased as well. On the other hand, the mechanical properties of fish gels with 0 and 1% salt content increased only when dairy proteins were utilized for filleting waste treatment. Sodium caseinate had a much greater effect on improving mechanical properties than whey protein, while microbial transglutaminase increased expressible water content (Uresti *et al.*, 2001).

Effluent from the second-stage anaerobic lagoon of a dairy industry was used as a medium for the growth of cyanobacterium *Arthrospira platensis* (blue-green algae) (Lincoln *et al.*, 1996). Algal growth was rapid and uninhibited at ammonia nitrogen (NH_3-N) concentrations lower than 75 mg/l, while growth was inhibited at concentrations higher of 100 mg/l. After 7 days, NH_3-N concentrations decreased from 100 mg/l to less than 1 mg/l, while the maximum removal rate was 24 mg/l/day. Algal biomass production was 70 g/m^3/day and half of the dry weight of biomass was edible protein. The potential of production of a protein feed as a by-product of dairy wastewater effluent treatment with cyanobacteria is a great perspective.

A synoptical presentation of various dairy industry waste treatment methods, physicochemical characteristics, applied substrate and final product/uses is summarized in Table 13.6.

Inputs and outputs in dairies

As for many other food processing operations, the main environmental impacts associated with all dairy processing activities are the high consumption of water, the discharge of effluent with high organic loads and the consumption of energy. Noise, odor and solid wastes may also be concerns for some plants (http://www.agrifoodforum.net/publications/guide/d_chp2.pdf).

In the dairy processing industry, water is used principally for cleaning equipment and work areas to maintain hygienic conditions and accounts for a large proportion of total water use. Most water consumed at dairy plants ultimately becomes effluent. Dairy plant effluent is generally treated to some extent on site and then discharged to municipal sewerage systems, if available. Dairy processing effluent includes predominantly milk and milk products which have been lost from the process, as well as detergents and acidic and caustic cleaning agents. Approximately 80% of a dairy plant's energy needs is met by the combustion of fossil fuels (coal, oil or gas) to generate steam and hot water for evaporation and heating processes (http://www.agrifoodforum.net/publications/guide/d_chp0.pdf).

Table 13.6 Dairy industry waste: treatment method and physicochemical characteristics, substrate to be applied and final product uses

No	Substrate to be applied	Treatment method	Physicochemical characteristics	Final product/uses	References
A Biogas/methane/hydrogen production					
1	Dairy waste water	Two-stage anaerobic/facultative waste stabilization pond system (loading rates 0.12 kg (BOD_5)/cow/day and 0.38 kg (VS)/cow/day, operation time 190 days, 13–15°C the first 60 days, 24°C at day 190)	1 Biogas detection: 137–190 days 2 Biogas production: 0.002–0.039 m^3/m^2/day	Biogas production	McGrath and Mason, 2004
2	Maize and dairy cattle manure	Anaerobic batch digestion at 38°C for 60 days	1 Dairy manure biogas and methane yield: 208.2–267.7 Nl/kg VS and 125.5–166.3 Nl CH_4/kg VS, respectively 2 Methane yield in late ripening maize varieties: 7100–9000 Nm^3 CH/ha 3 Methane yield in early and medium ripening varieties: 5300–8500 Nm^3 CH_4/ha	Biogas/methane production	Amon *et al.*, 2006
3	Dairy cow manure	Gasification at high temperatures (slagging mode of operation: 1350–1400°C, non-slagging operation: 800–900°C)	1 Syngas composition: CO, H_2, and N_2 2 Gasification conversion efficiencies: 65–85%	Syngas utilization for electricity and heat generation, or for other energy needs, thus reducing the operating costs of the farm	Young and Pian, 2003
4	Cattle slurries	Anaerobic batch digestion cattle slurries and solid wastes at 120 rpm and 35°C	1 VS reduction: 45–55% 2 The highest cumulative methane production: co-digestion of cattle slurry with fruit and vegetable waste 3 Highest specific gas yield: co-digestions of cattle manure and fish offal or brewery sludge (0.38 and 0.31 m^3 CH_4/kg VS removed, respectively) 4 Lowest specific gas yield: co-digestion of cattle manure with food and vegetable waste or chicken manure (0.13–1.16 m^3 CH_4/kg VS removed) 5 Increase in N concentration	Methane production	Callaghan *et al.*, 1999
5	Dairy manure	Coagulation/flocculation (coagulant: calcium oxide (CaO), flocculant: cationic polyacrylamide)	1 Solid fraction: 75.2% TS, 80.4% VS, 58.6% TKN, 87.4% TP 2 Liquid fraction: 21.8% TS, 17.0% VS, 39.5% TKN and 10.8% TP 3 Specific methane production: 0.307 (dairy manure), 0.371 (screened	Methane production	Rico *et al.*, 2007

(*Continued*)

Table 13.6 (*Continued*)

No	Substrate to be applied	Treatment method	Physicochemical characteristics	Final product/uses	References
			manure) and 0.604 (liquid fraction) L NCTP CH_4/g VS		
6	Fresh crude (unskimmed) cheese whey	Fermentation by *Clostridium saccharoperbutylacetonicum* (pH 5–10, 30°C, agitation speed 50 rpm)	At pH 6: highest H_2 production (1432 ml), yield (7.89 mmol/g lactose) and the maximum production rate (47.07 ml/h)	Hydrogen production	Ferchichi *et al.*, 2005
B Fertilizer					
7	Dairy slurry	Soil application of slurry from cows fed with either ryegrass or maize	1 Higher water-soluble organic carbon (WSOC) content 2 Stable microbial biomass (SMB) carbon content 3 Higher urease, cellobiohydrolase, β-N-acetyl-glucosamidase, β-glucosidase and acid phosphatase activities in soil	Amendment	Bol *et al.*, 2003
8	Dairy effluent	Bioremediation with *Wollfia arrhiza* (pteridophyte) for 15 days	Reductions up to 74% in BOD, 72% in COD, 58% in total available nitrogen (TAN) (NH_4^+-N, NO_2^--N, NO_3^--N) and 76% in available phosphorus (TP) (PO_4^{2-}-P)	In aquaculture as a fertilizer with proper dilution	Mishra *et al.*, 2000
9	Dairy sludge	Straw, two green waste composts, sawdust, paper sludge and tannic acid were mixed with celery leaves (*Apium graveolens* L.) for nitrogen (N) immobilization from crop residues. Malting sludge, vinasses, molasses and dairy sludge were added for immobilized N remineralization	1 Fastest N immobilization: with straw (30.2 mg N/kg) 2 Slowest N immobilization: with tannic acid, sawdust and GWC1 (16.4, 15.9 and 8.0 mg N/kg, respectively) 3 No N immobilization: with paper sludge and GWC2 4 N remineralization: with a mixture of green compost and vinasses (55.4 mg N/kg)	Organic biological waste can be used for nitrate concentration reduction in soil	Chaves *et al.*, 2005
10	Cattle slurry	Thermophilic aeration of cattle slurry, whey and/or jam wastes in a heat-insulated reactor with retention times of 4–5 days (winter: 0–−21°C, summer: 20°C)	Increase of soil organic matter content	1 Heat: for preheating the water, which is needed in a farm household and for washing of milking product 2 Final product: fertilizer and soil improving compound	Heinonen-Tanski *et al.*, 2005
11	Dairy effluent	Addition of the effluent to pots planted with perennial ryegrass (*Lolium perenne* L.) seeds (20°C, with 16 h light/8 h dark)	1 Decline of dry matter content with increasing effluent rate (after 32 days of application) and increase of shoot dry matter with increasing effluent rate (after 130 days)	Soil application	Sarathchandra *et al.*, 2006

			2 Decrease in nitrogen and sulfur concentration in shoots and increase of phosphorus concentration 3 Increase of pathogenic fungi population in roots and decrease of diversity and species richness of total fungi 4 Increase of root pathogens (*Fusarium oxysporum*, total *Fusarium* spp. and *Pythium* spp.) and decrease of *Codinaea fertilis* (after 130 days)		
12	Dairy slurry	1 Anaerobically digested dairy slurry mixed with dry chemical extinguishing agents (1% or 4%, w/w/) was added to orchard grass 2 Raw and anaerobically digested slurry mixed with animal bone ash was added to dent corn	1 Orchard grass: largest dry matter yield with 4% chemical extinguishing agents 2 Dent corn: increased with increase in amount of bone ash	Application to agricultural land	Tani *et al.*, 2006
13	Dairy manure or compost	Dairy manure or compost with and without alum ($Al_2(SO_4)_3$) applied to 0–10 cm soil depth and on fresh potato skins	1 Dairy compost or manure: *E. coli*, *Enterococcus* spp. and fecal coliform populations remained stable 2 Dairy manure: increase of *Enterococcus* spp. and fecal coliform populations in potato rhizosphere, higher *Enterococcus* spp. and fecal coliform populations in fresh potato skins 3 Dairy waste, compost and alum: *Enterococcus* spp. and fecal coliform numbers remained stable 4 No detection of *E. coli*	Soil application	Entry *et al.*, 2005
14	Dairy manure	Composting in windrows at 55–70°C for 4 months with wheat straw or sawdust (mostly *Quercus* spp.)	1 Compost sampled 0, 14 and 28 days inhibited cucumber growth 2 Mature composts increased shoot dry weight 3 Fresh dairy-straw compost increased shoot nitrogen (N) concentration from 2.4 to 4.0% 4 Dairy manure-wheat straw treatments: low Ca concentration (0.6–0.8%) 5 Dairy manure-sawdust treatments: low N (1.5–2.0%), Ca (0.6–0.7%) concentration, sufficient Mo concentration (0.4–1.0%)	Substrate for cucumber (*Cucumis sativus* L.) seedlings emergence and growth	Wang *et al.*, 2004

(*Continued*)

Table 13.6 (*Continued*)

No	Substrate to be applied	Treatment method	Physicochemical characteristics	Final product/uses	References
15	Feces and urine of dairy cows with bedding material and straw	Composting in windrow piles for 2 months under controlled aeration and moisture conditions (compost treatments: no turning/no watering, no turning/watering, turning/no watering and turning/watering)	1 Increase in inorganic NO_3^--N accumulation in soils amended with mature compost 2 Higher soil mineralization at higher rates of composts (which were turned) added to the soil 3 Inorganic N accumulation did not differ among soils mixed with immature compost	N-fertilizer	Shi *et al.*, 1999
16	Dairy manure effluent	Treatment by algal turf scrubber technology	Algal biomass: rich in nutrients, pathogen elimination, low heavy-metal content, easily ground for different formulations	1 Compost: land application 2 Biomass from the algal scrubbers: feed supplement or organic fertilizer or exported from farm 3 Energy: for biomass drying, pumping water and repayment of capital investment	Pizarro *et al.*, 2006
C Animal feedstuff					
17	Cow manure	Gamma irradiation at dose rates of 5–25 kGy	1 Body gain of chicks fed with non-irradiated and irradiated manure was less than control diet by 11.8%, 6.8% and 5.6%, respectively 2 Mean body weight of chicks fed with untreated and irradiated manure was less than those fed with control diet by 10.9%, 6.4%, and 5.2%, respectively	Feedstuff for chicks	Dia El-Din *et al.*, 1999
18	Dairy products (cheese)	*P. camemberti* and *P. roqueforti* strains obtained from dairy products inoculated in bergamot fruit peel pieces and incubated at 25°C for 10 days	Increase in crude protein, ether extract, gross energy and structural carbohydrates (neutral detergent fiber, acid detergent fiber, hemicellulose, cellulose)	Citrus fruit peel can be used as an animal feed	Scerra *et al.*, 1999
19	Dairy by-products (cheese whey, lactose mother liquor)	1 Addition of four proteolytic microorganisms (pH 6.0, 30°C, 40 h) and lactic acid bacteria cultures (37°C) 2 Addition of proteolytic enzymes (alcalase and flavorenzyme) ($pH > 5.5$, 30–40°C)	1 Proteolytic microorganisms: complete conversion of lactose to lactic acid 2 Protease enzymes: fastest acid production	Animal feed	Vasala *et al.*, 2005

D Food industry					
20	Fish stomach mucosa	Isolation of tuna fish gastric proteases using 25% NaCl at different holding times (0–3 h), prior to the enzyme activation at pH 5.0	–	Rennet substitutes for cheese manufacture	Tavares *et al.*, 1997
21	Milk or whey	Concentration by evaporation (20°C), followed by pre-crystallization of raw lactose, lactose purification by ultrafiltration (UF) and diafiltration (DF), permeate separation from monovalent salts by nanofiltration (NF)	–	1 Whey or whey protein concentrates: sweet and salt foodstuff, extraction of vegetables and fruits, instant flours and additives for soups 2 Lactose, minerals and vitamins: in dietetic foodstuff for diabetics and hypertensive patients	Ostojic *et al.*, 2005
22	Cottage cheese whey	Decantation, heating (65°C), filtration, heating (65°C, 60 min) for pasteurization and calcium precipitation, filtering, cooling pasteurization (75°C, 15 s), storage (5°C)	Concentrate: 17.8% total solids (TS) increase and 16.3% sodium concentrate decrease, 1.2% fat, 2.4% protein, and 19.7% lactose	Concentrate: use in dairy products (ice-cream and yogurt) and conversion into sweet syrup for use in other products	Nguyen *et al.*, 2003
E Miscellaneous uses					
23	Paste from filleting waste of silver carp (*Hypophthalmichthys molitrix*)	Mixture with microbial transglutaminase, dairy proteins (whey protein and sodium caseinate) and NaCl (2 min, 15°C), spraying with vegetable oil, immersion in water (40°C 1 h, 90°C 20 min)	Salt levels: 0–2%	Increase in fish mechanical properties	Uresti *et al.*, 2001
24	Dairy effluent	Second-stage anaerobic lagoon treatment. Used as a medium for cyanobacterium *Arthrospira platensis* growth	1 Rapid and uninhibited algal growth: at nitrogen (NH_3-N) concentrations <75 mg/l 2 Algal growth inhibition: at NH_3-N concentrations >100 mg/l 3 Reduction of NH_3-N concentrations 100 mg/l to less than 1 mg/l (after 7 days) 4 Maximum removal rate: 24 mg/l/day 5 Algal biomass production: 70 g/m^3/day	1 Medium for the growth of cyanobacterium *Arthrospira platensis* 2 Production of a protein feed	Lincoln *et al.*, 1996

Table 13.7 Inputs and outputs in the dairy industry

Nutrient balance on farm	**Inputs**						**Outputs**					
	Conventional farm (kg/ha)			**Organic farm (kg/ha)**			**Conventional farm (kg/ha)**			**Organic farm (kg/ha)**		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Feed and seeds	134	19.8	46	29	5.2	9						
Products							47	9.5	14	20	4.1	6
Fertilizers	86			0								
N-fixation	15			46								
N-deposition	10			85								
Nutrient surplus							198	10.3	32	65	1.1	3
Milk production process												
Water (l)	4.4											
Electricity (kWh)	0.0463											
Packaged milk (l)							1					
Cream (g)							22.3					
Solid (combustion) waste (g)							2.2					
Emissions to air												
SO_2 (g)							0.2					
NO_2 (g)							3.5					
CO (g)							3.8					
Emissions to water												
1 Wastewater (l)							0.2					
COD (g/L)							0.02					
TSS (g/L)							0.02					
Emissions to soil												
1 Sludge (l)							0.05					
Fe (mg/l)							12.9					
Cr (mg/l)							0.38					
Hg (mg/l)							0.008					
Zn (mg/l)							2.9					
Cleaning												
							Water consumption (l per cleaning)			**Energy consumption (kWh per cleaning)**		
Conventional alkaline/ acidic cleaning							1000			110		
One-phase alkaline cleaning							1000			75		
Enzyme-based cleaning							900			65		
pH-2 method							900			85		

Adapted from Cederberg and Mattsson, 2000; Eide *et al*., 2003;[**13.6] Hospido *et al*., 2003

Hardly any solid waste is produced by the dairy industry. The main solid wastes produced by the dairy industry are packing material (paperboard cartons, plastic containers, etc.) and sludge resulting from wastewater purification (http://www.fao.org/WAIRDOCS/LEAD/X6114E/x6114e06.htm#4.%20DAIRY%20INDUSTRY; http://www.fao.org/WAIRDOCS/LEAD/X6114E/x6114e07.htm#b3-5.3.%20Treatment%20of%20wastewater).

Emissions to air from dairy processing plants are triggered by the high levels of energy consumption necessary for production (pasteurization, sterilization, drying etc.). Air pollutants, including oxides of nitrogen and sulfur and suspended particulate matter, are formed from the combustion of fossil fuels, which are used to produce both these energy sources. For operations requiring the use of refrigeration systems based on chlorofluorocarbons (CFCs), the release of these gases to the atmosphere is an important environmental consideration, since CFCs are recognized to be a cause of ozone depletion in the atmosphere (http://www.agrifood-forum.net/publications/guide/d_chp2.pdf).

The principal causes of continuous noise include air discharges from drier stacks, heater fans, air supply fans, ventilation, boilers, pumps, cooling towers, refrigeration units and aerators on aerated lagoons. Noisy operations at dairy plants also include milk drying, which requires high airflows, and the movements of transport vehicles to and from the site (http://epanote2.epa.vic.gov.au/…/2f1c2625731746aa4a256ce90001cbb5/455a88b76f16a8254a2565fc0008e51b/$FILE/570.pdf).

Odors in and around milk processing plants come from the biological decomposition of milk derived organic matter, generally found in wastewater. Often these odors are due to poor housekeeping, overloaded or improperly run wastewater treatment and disposal facilities and prolonged storage of strong wastes such as whey. Particle emissions are caused either by combustion of solid or liquid fuel or, more often, spray drying of milk and whey (http://epanote2.epa.vic.gov.au/…/ 2f1c2625731746aa4a256ce90001cbb5/455a88b76f16a8254a2565fc0008e51b/$FILE/570.pdf).

Hazardous wastes consist of oily sludge from gearboxes of moving machines, laboratory waste, cooling agents, oily paper filters, batteries, paint cans etc. (http://www.agrifood-forum.net/publications/guide/d_chp2.pdf).

Inputs and outputs of various dairy industry processes are summarized in Table 13.7.

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