A Review on the Dairy Industry Waste Water Characteristics, Its Impact on Environment and Treatment Possibilities

Surbhi Sinha, Abhinav Srivastava, Tithi Mehrotra, and Rachana Singh

Abstract Dairy industry is one of the most polluting industries in India. Due to the elevated milk demand, the dairy industry in India has developed swiftly, leading to a large amount of waste discharge in the nearby water bodies. The waste water from dairy industry is characterized by high BOD, COD, organic and inorganic contents. Release of these waste waters into the water bodies without suitable remediation can cause serious environmental issue. Indian government has enforced very stern rules and regulations for the waste water discharge to safeguard the environment. Therefore, suitable methods are needed to meet the effluent discharge standards. This chapter thus discusses the various sources and characterization of dairy waste water, their impact on the environment and the conventional as well as the improved techniques for the treatment of dairy waste water.

Keywords Dairy industry · Sources · Characteristics · Treatment · Advanced treatment technologies

1 Introduction

Dairy industry is considered to be one of the major industries of food sector playing an important role in the economy of the country. India has attained first position in milk production, out of all the milk-producing nations and is sharing about 13.1% of the total milk produced in the world (Kumbhar 2010). Dairy industry is believed to have a notable effect on the water pollution as there are about 286 large- and small-scale dairy industries in India accountable for plenty of waste production, both in solid and liquid form (Kothari et al. 2012). Approximately, 110 million tons of milk and 275 million tons of waste water are released annually from the indian dairy industries (Kushwaha et al. 2011). Expeditious expansion of dairy industries has not only increased the efficiency of work rate but has also resulted in the production and discharge of dangerous stuff into the environment, consequently

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T. Jindal, *Emerging Issues in Ecology and Environmental Science*,
SpringerBriefs in Environmental Science, https://doi.org/10.1007/978-3-319-99398-0_6

Table 1 Minimal standards for discharge of effluent from dairy industry (Bharati and Shinkar 2013a, b)

Parameters	World Bank Report	CPCB, India
pH	6–9	6.5–8.5
BOD_5	50	100 (Based on BOD_1)
COD	250	–
TSS	50	150
Oil and grease	10	10
Total nitrogen	10	–
Total phosphorous	2	–
Temperature increase	≤3 °C	–

Except pH, all parameters are in terms of mg L^{-1}

causing health hazards and affecting flora and fauna. The dairy industry is one of those sectors where the cleaning tanks, homogenizers, pipe sand, heat exchangers and other equipment release a huge amount of effluents with a high organic load. This organic load is basically constituted of milk (raw material and dairy products), reflecting effluent with high levels of chemical oxygen demand (COD), biochemical oxygen demand (BOD), oil and grease, nitrogen and phosphorus (Srivastava et al. 2016). This demands rapid and efficient treatment of the waste water before being discharged into the environment. Water management in dairy industry is well recognized, but production and disposal of effluent remains a challenging subject. The Indian government has enforced very stern rules and regulations for the discharge of effluent in order to protect the environment (Table 1). Accordingly, suitable techniques should be used by the industries to meet the effluent discharge standards.

To facilitate dairy industry to contribute in water conservation, development of a well-organized and cost-effective technique is essential. In order to have proper processes in the effluent treatment plant, characterization of waste water, treatability studies and planning of proper units and processes for effluent treatment is very much necessary.

2 Sources of Dairy Waste Water

Effluent from the dairy industry emerges from the following parts of the plant: receiving station, cheese plant, bottling plant, casein plant, butter plant, dried milk plant, condensed milk plant and ice cream plant. Waste from the dairy is also generated from the washing and cleaning out of the product remaining in the cans, trucks, pipes or other equipments. Spillage of the products due to overflows, leaks, careless handling, boiling over also are sources of the dairy waste. Moreover, sludge discharge from settling tank or discharges from the bottles and detergents used in washing also lead to the origin of dairy waste.

Table 2 Characteristics of dairy industry waste water

Waste type	COD	BOD	pH	TSS	TS	References
Dairy effluent	1900–2700	1200–1800	7.2–8.8	500–740	900–1350	Sukhadev et al. (2013)
Milk and dairy products factory	10,251.2	4840.6	8.34	5802.6	–	Cristian (2010)
Arab dairy factory	3383 ± 1345	1941 ± 864	7.9 ± 1.2	831 ± 392		Tawfik et al. (2008)
Whey	71,526	20,000	4.1	22,050	56,782	Deshpande et al. (2012)
Cheese whey pressed	80,000–90,000	1,20,000–1,35,000	6	8000–11,000		Tikariha and Sahu (2014)
Aavin dairy industry wash water	2500–3300	–	6.4–7.1	630–730	1300–1400	Sathyamoorthy and Saseetharan (2012)

Except pH, all parameters are in terms of mg L^{-1}

3 Characteristic of the Dairy Effluent

The effluent from dairy industry contains plenty of milk constituents such as casein, inorganic salts besides sanitizers and detergents used for washing. It also has dissolved sugars, fats, proteins and possibly residues of additives. Dairy waste water is characterized by intense smell, high COD, BOD, dust and variable pH (Kothari et al. 2011). The waste load equivalent of specific milk constituents are as follows: 1 kg of milk fat = 3 kg of COD; 1 kg of lactose = 1.13 kg of COD; 1 kg of protein = 1.36 kg of COD (Kasmi et al. 2017). It contains adequate amount of nutrients like nitrogen (14–830 mg L^{-1}) and phosphorous (9–280 mg L^{-1}) which can promote the growth of pathogens (Rico Gutierrez et al. 1991). Additionally, it has dissolved solids, suspended solids, chlorides, sulphates, oil, and grease. Typically, the characteristics of dairy effluent largely depend on the quantity of milk processed and the product manufactured. Table 2 shows the typical characteristics of dairy effluent reported by various authors.

4 Effects of Dairy Effluent on Environment

Waste generated from dairy industry contains highly putrecible organic constituents (Qasim and Mane 2013). The organic constituents present in the dairy waste water putrefy fast, diminishing the level of dissolved oxygen in the receiving water bodies creating anaerobic conditions and intense foul odour. Also, the receiving water becomes breeding place for mosquitoes and flies which can cause threatening diseases like malaria, chikungunya, and dengue (Kumar and Desai 2011). The dairy effluent contains loads of milk components like inorganic salts, casein along with detergents and sanitizers used for washing. All these constituents are basically responsible for the increase in high BOD and COD (Singh et al. 2014) of the water, which surpasses the permissible limit set by Bureau of Indian Standard (BIS). The casein precipitation from the dairy waste decomposes further into odorous black sludge. Additionally, dairy wastes are also hazardous to certain fish. These effluents promote the growth of certain algae and bacteria which eventually utilize oxygen present in the water, consequently leading to the death of fish due to suffocation. Dairy industries result in the emission of toxic gases like carbon dioxide, sulphur oxides and nitrogen oxide to the atmosphere. Furthermore, methane is released during anaerobic treatment and nitrous oxide from the soil at dairy waste waster irrigation sites. Carbon dioxide, methane and nitrous oxide are greenhouse gases, and their increased emission can lead to global warming. Global warming in turn would affect the environment in many ways including increased melting of snow and ice, rise in sea level, and desertification. Apart from global warming, these greenhouse gases also lead to ocean acidification, ozone depletion, smog pollution as well as changes to plant growth and nutrition. Dairy industries also emit particulate material in the atmosphere leading to increase in dust which settles down on the surrounding building, making them vulnerable to corrosion.

5 Dairy Waste Water Treatment

Treatment methods generally used in dairy industry are the following.

5.1 Mechanical Treatment

This is the initial phase of the dairy waste treatment and involves screens, grit chambers, skimming tank or sedimentation tank. The screens are in the inclined position with the direction of the flow. The large materials floating in the water bodies or effluent are removed by screens; or else they can choke up the small pipes which can further affect the working of effluent pumps. Grit chambers can remove the heavier inorganic particles such as grit and sand. Skimming tanks are used to remove oil, grease, fruit skins, wood pieces, etc. A sedimentation tank allows suspended particles to settle out of waste water as it flows slowly through the tank. Sludge is formed at the bottom of the tank which is further again treated to make it less toxic (Patel et al. 2016).

5.2 Chemical Treatment

Chemical treatment involves the technique of precipitation. The method requires the addition the flocculants like aluminium salt, iron salt, and lime to the waste water and strenuous mixing using agitators. This leads to the precipitation of inorganic phosphate in the form of very fine particles which then combine together to form larger flocks. These flocks then sit down at the bottom of the sedimentation tank as primary sludge, whereas the clear effluent passes into the basin for biological treatment (Birwal et al. 2017).

5.3 Biological Treatment

Biological treatment often referred to as secondary treatment is used to remove materials left after primary treatment. It is considered to be one of the dependable methods for the dairy effluent treatment. Since dairy waste water mainly comprises organic waste, biological treatment method is the favourable choice for the removal of these organic wastes as these methods utilize soluble compounds and small colloids. Based on oxygen requirements, biological treatments are of two main types: aerobic and anaerobic (Sengil and Ozacar 2006).

In aerobic biological treatment system, the micro-organisms in the presence of oxygen oxidize organics to carbon dioxide and water, whereas anaerobic system is generally used for the treatment of high strength dairy waste water where micro-organisms in the absence of oxygen convert organic matter and nutrients to methane and CO_2, while the rest of biomass is used for cell growth and maintenance. Table 3 compares the various advantages and disadvantages of aerobic and anaerobic treatment system for dairy waste water.

These days generally aerobic systems are used for the treatment of dairy effluent, but there are number of drawbacks associated with these processes. High energy requirement, filamentous growth and rapid acidification due to high lactose level and low water buffer capacity are the some of the downsides related with aerobic systems. Anaerobic systems however are more reliable for the treatment of dairy waste water loaded with a high organic content. This process of treatment is a cost-effective process as it does not require aeration or large area and generates vey less amount of sludge.

Table 3 Comparison of advantages and disadvantages of aerobic and anaerobic treatment of dairy industry waste water (Bharati and Shinkar 2013a, b)

Factors	Aerobic process	Anaerobic process
Reactors	Aerated lagoons, stabilized ponds, trickling filters, biological discs	UASB, anaerobic filter upflow packed bed reactor, CSTR downflow fixed film reactor
Reactor size	Large size	Smaller reactor size
Energy	High energy is required	These processes produce energy in the form of methane
Biomass yield	6–8 times greater biomass is produced as compared to anaerobic process	Lower biomass is produced
Shock loading	Excellent performance in this regard	Not very good response to shock loading

6 Advanced Technologies for Dairy Effluent Treatment

6.1 Physicochemical Process

Electrocoagulation

Electrocoagulation is one of the advanced alternative processes for the treatment of dairy waste water. It is carried out by employing the electric current across the metal plates immersed in water. Organic and inorganic wastes, heavy metals, colloidal particles, etc. are primarily held in water by electrical charges. By applying another electrical charge to the contaminated water, the charges that hold the particles together are destabilized and separate from the clean water. The particles then coagulate to form a mass, which can be easily removed. This process is a low sludge producing technique. Above all, waste waters treated by electrocoagulation are clear, palatable, colourless and odourless. However, the use of electricity makes it an expensive process. Sharma (2014) removed COD and oil from dairy waste water using electrocoagulation. The batch experimental results showed 87% of COD removal at 3 A, pH 9 and electrolysis time of 75 min. Shivayogimath and Vijayalaxmi (2014) used electrocoagulation technique for the dairy waste water treatment. During the study they found that 98.75% COD and 97.82% turbidity can be removed with very short electrolysis duration of 10 min at applied voltage of 7 V and pH 6. Gerson de Freitas Silva et al. (2015) studied the efficiency of electrocoagulation using aluminium electrodes in treating waste water from a dairy industry. They reported 57% COD removal, 99% turbidity removal and 92% removal of total suspended solids at pH 5 and current density of 61.6 A m^{-2} (Fig. 1).

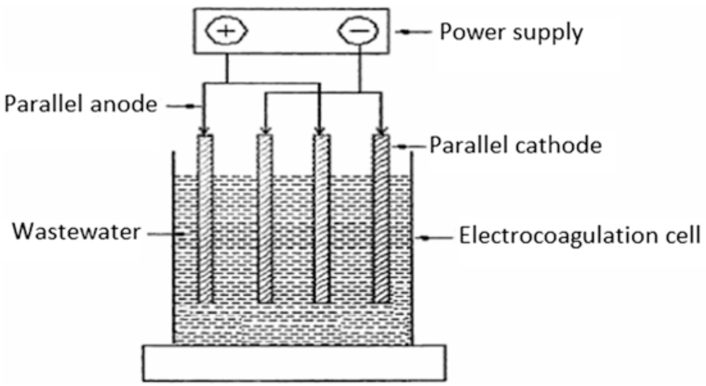

Fig. 1 Schematic design of electrocoagulation Reactor. Source: Dehghani et al. (2015)

Adsorption

Adsorption is a waste water treatment technique used for eliminating large number of non-degradable organic compounds from waste water. Activated carbon is the most widely used adsorbent for the treatment of waste water. Some low cost adsorbents like rice husk, coal fly ash and straw dust are also used for the treatment of waste water. Pathak et al. (2016) used rice husk as an adsorbent for the removal of organic pollutants from dairy effluent. Maximum removal of as high as 92.5% could be achieved using an adsorbent dosage 5 g L^{-1}, pH 2, and temperature 30 °C. Marol et al. (2017) treated dairy waste water using sugar bagasse ash and rice husk as adsorbents. Kanawade and Bhusal (2015) used activated charcoal for the treatment of dairy waste water. Activated charcoal removed a maximum of 65% COD and 67% BOD from dairy effluent.

Membrane Treatment

Membrane separation plays an imperative role in waste water treatment, water reclamation and desalination applications. The common membrane separation processes like microfiltration, ultrafiltration, nanofiltration, reverse osmosis and electrodialysis are used to remove contaminants from dairy waste water. These processes function effectively at low temperatures and low energy requirements. Above all, high feasible product recovery is possible. However, equipment costs are high and fouling of membrane takes place which can lead to decrease in the flux of permeates. Zielińska and Galik (2017) removed approximately 90% of COD from dairy waste water using micro filteration system. A high-performance bioreactor, an aerobic jet loop reactor, combined with a ceramic membrane filtration unit, was used to investigate its suitability for the treatment of the dairy processing waste water. A loading rate of 53 kg COD m^{-3} d^{-1} resulted in 97–98% COD removal efficiencies fewer than 3 h hydraulic retention time (Burhanettin and Suleyman 2011). Andrade et al. (2015) evaluated the technical and economic feasibility of membrane bioreactors followed by nanofiltration for dairy waste water treatment in order to reuse the treated effluent. It was observed that the membrane bioreactors efficiently removed the organic matter and colour of the feed effluent (Fig. 2).

6.2 Aerobic Treatment

Sequencing Batch Reactor (SBR)

SBRs are one of the most promising types of activated sludge treatment where the entire treatment process takes place in a set of tanks that usually run on a fill and draw basis. The tanks may be a rectangular basin, an earthen or oxidation ditch, or any other concrete/metal type structure. This technique treats the waste water in

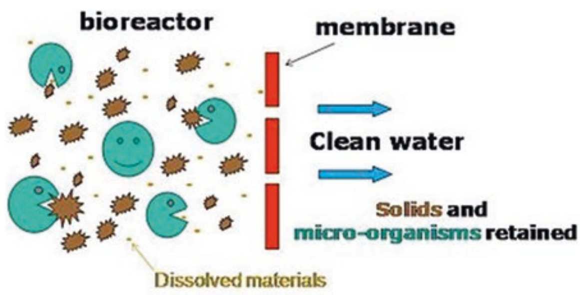

Fig. 2 Simple schematic describing the membrane bioreactor process. Source: Le-Clech et al. (2006)

batch mode and each batch is sequenced through a series of treatment stages. Each tank in the SBR is filled with the waste water and mixed with biomass. Aeration is provided to the tank to encourage biological growth and waste reduction. After a discrete period of time, both mixing and aeration are stopped and the solids are allowed to settle down at the bottom of the tank while clarified effluent is decanted. This process is simple and the quality of effluent after treatment is high. Moreover, it reduces main pollutants like ammonia and phosphate. However, sludge must be disposed off frequently and it sometimes becomes difficult to adjust cycle times for small communities. Mohseni-Bandpi and Bazari (2004) investigated a bench-scale aerobic SBR to treat the waste water from an industrial milk factory. The results showed 90% of COD removal in all conditions. Li and Zhang (2002) investigated the performances of single-stage and two-stage sequencing batch reactor (SBR) for treating dairy waste water. It was found that two-stage system consisting of an SBR and a complete-mix biofilm reactor was capable of achieving complete ammonia oxidation and comparable carbon, solids, and nitrogen removal while using at least 1/3 less HRT as compared to the single SBR system (Fig. 3).

6.3 Anaerobic Treatment

Upflow Anaerobic Sludge Blanket (UASB)

Upflow anaerobic sludge blanket reactor is one of the most widely used anaerobic digesters for the treatment of industrial waste water. It is a single tank process consisting of anaerobic micro-organisms for the treatment of industrial waste water, resulting in almost complete removal of organic pollutants. Waste water infiltrates the reactor from the bottom and then flows upward. A suspended sludge blanket in the reactor treats the waste water as it flows through it. Micro-organisms in the sludge break down the organic matter present in the waste water by anaerobic digestion into methane and carbon dioxide. Sludge production is low as compared to aerobic treatment system due to the slow growth rate of anaerobic organisms and good removal efficiency is achieved even at high loading rates and low temperatures. Howbeit, pathogens are only partially removed in the UASB reactor and

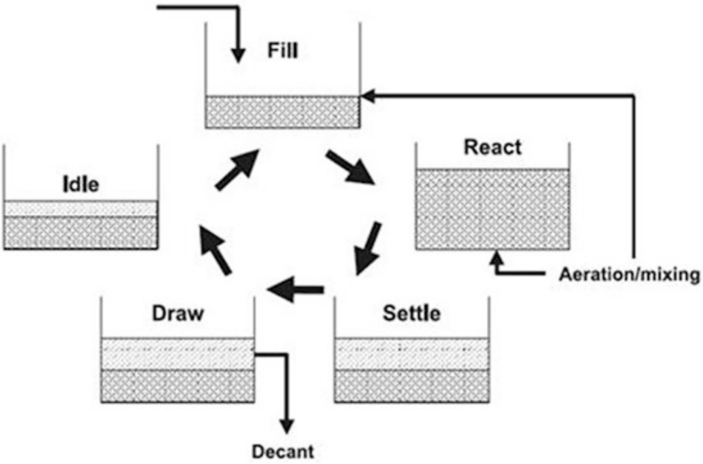

Fig. 3 Typical cycles of SBR. Source: USEPA (1999)

production of hydrogen sulphide during the treatment can lead to bad smell and corrosion. Gavala et al. (1999) treated dairy waste water using an upflow anaerobic sludge blanket reactor. They found that operation at an organic loading rate of 6.2 g COD L^{-1} d was found to be safe and could be increased to a maximum of 7.5 g COD L^{-1} d and COD reduction of 90% at organic loading rate of 0.031 kg COD m^{-3} d was achieved operating in steady-state conditions using a waste water with a COD influent of 2050 mg L^{-1}. UASB reactor was used for the treatment of dairy waste water by Kavitha et al. (2013). COD and BOD removal of 77% and 87%, respectively was achieved in the reactor (Fig. 4).

Anaerobic Sequencing Batch Reactors (ASBR)

ASBR is a newly developed batch reactor system that includes digestion and separation of solids within a single vessel. ASBR follows four steps for the treatment of waste water: feeding, reaction, settling and withdrawal of treated effluent. These reactors are extensively used because of their merits like these are simple, have efficient quality control of effluents, diminishes the settling step for both affluent and effluent and also can be used to treat a variety of effluents. However, one major limitation with ASBR is that they do not perform well when overloaded. Abdulsalam et al. (2011) treated synthetic milk waste water in anaerobic sequence batch reactor. The percentage COD reduction at 35 °C with additional seeds has been observed at the lower organic loading 1 g L^{-1} and retention time of 72 h to be 83.33%. In one lab-scale study, thermophilic ASBR and mesophilic ASBR systems provided volatile organic solid removal between 26% and 44%, and between 26% and 50% for dairy waste water respectively (Nadais et al. 2005). In another lab-scale study, 62% and 75% removal rate of COD and BOD was observed at a hydraulic retention

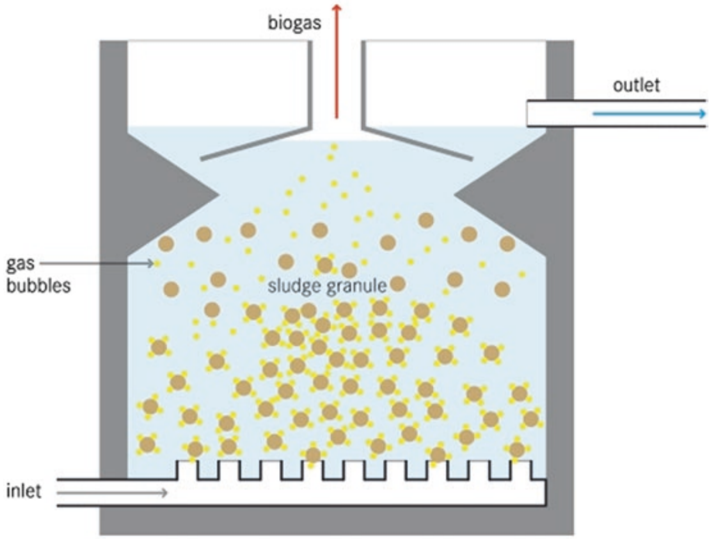

Fig. 4 Schematic diagram of an upflow anaerobic sludge blanket reactor (UASB). Source: Tilley et al. (2014)

time (HRT) of 6 h, at 58 °C, for a substrate containing non-fat dry milk (Dugba and Zhang 1999).

7 Conclusion

Dairy waste water causes serious water pollution and harms the entire ecosystem, and its treatment therefore becomes a primary need for industries. Industries can use techniques that are inexpensive and can be operated with minimum supervision. Biological methods are considered to be most effective for the treatment of dairy waste water, where aerobic systems are easier to operate and control and anaerobic systems produce less amount of sludge with lower energy requirement. Since none of the techniques alone is capable of treating the dairy waste water efficiently, a combined process can be developed specifically to treat the dairy waste water complying with the minimum effluent discharge requirement.

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