Impact of Dairy Effluent on Environment—A Review

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Abstract Dairy industry is among the most polluting of the food industries in regard to its large water consumption. Dairy is one of the major industries causing water pollution. Considering the increased milk demand, the dairy industry in India is expected to grow rapidly and have the waste generation and related environmental problems are also assumed increased importance. Poorly treated wastewater with high level of pollutants caused by poor design, operation or treatment systems creates major environmental problems when discharged to the surface land or water. Various operations in a dairy industry may include pasteurization, cream, cheese, milk powder, etc. The dairy industry handles large volumes of milk and the major waste material from processing is the water. The water removed from the milk can contain considerable amounts of organic milk products and minerals. In addition cleaning of plant, results in caustic wastewater. This review article discusses the impact of wastewater released in the environment, methods to minimise the amount of both the organic and inorganicmaterial in the wastewater and waste water treatment.

Keywords Dairy effluent · Pollution · Impact

1 Introduction

Waste water generated in a dairy contains highly putrescible organic constituents. This necessitates prompt and adequate treatment of the waste water before its disposal to the environment. Almost all the organic constituents of dairy waste are easily biodegradable. Hence, the wastewater is amenable to biological treatment, either aerobic or anaerobic. Rapid growth of industries has not only enhanced the

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productivity but also resulted in the production and release of toxic substances into the environment, creating health hazards and affected normal operations, flora and fauna. These wastes are potential pollutants when they produce harmful effects on the environment and generally released in the form of solids, liquid effluents and slurries containing a spectrum of organic and inorganic chemicals. Effluent treatment in industries to meet the discharge standards mentioned by pollution control board has always been a great problem for the industrialists. Before discharging the treated effluent on to the land or any surface water body the industries should meet the effluent discharge standard norms. 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 (Barnett et al. 2010).

2 Wastewater and Their Sources

Wastes from milk product manufacture contain milk solids due to varying concentration and in dilute condition. These solids enter the waste from almost all of the operations. In general, the wastes generated from dairy industry are as follows,

- The washing and cleaning out of product remaining in the tank, trucks, cans, piping, tanks and other equipment is performed routinely after every processing cycle.
- Spillage is produced by leaks, overflow, freezing-on, boiling over and careless handling.
- Processing losses include, sludge discharge from settling tank, discharges from bottles and washers, splashing and container breakage in automatic packaging equipment.
- Detergents and other compounds are used in the washing and sanitizing solution that are discharged as wastes.

3 Characteristics of the Effluent

The characteristics of a dairy effluent contain temperature, color, pH (6.5–8.0), BOD, COD, dissolved solids, suspended solids, chlorides, sulphate, oil and grease. It depends largely on the quantity of milk processed and type of product manufactured. The waste water of dairy contains large quantities of milk constituents such as casein, inorganic salts, besides detergents and sanitizers used for washing. It has high sodium content from the use of caustic soda for cleaning (Ferguson 1976). Typical characteristics of dairy industry wastewaters reported by various authors are given in Table 1.

Table 1 Characteristics of dairy industry wastewaters (composition in mg/l, except pH)

Waste type	COD (mg/l)	BOD (mg/l)	pH	TSS (mg/l)	TS (mg/l)
Milk and dairy products factory	10251.2	4840.6	8.34	5802.6	–
Dairy effluent	1900–2700	1200–1800	7.2–8.8	500–740	900–1350
Dairy waste water	2500–3000	1300–1600	7.2–7.5	72,000–80,000	8000–10,000
Dairy effluent (CPCB 1993)	1120–3360	320–1750	5.6–8	28–1900	–
Whey	71,526	20,000	4.1	22,050	56,782
Cheese whey pressed	80,000–90,000	120,000–135,000	6	8000–11,000	1
Aavin dairy industry washwater	2500–3300	–	6.4–7.1	630–730	1300–1400
Dairy industry wastewater	2100	1040	7–8	1200	2500

4 Effects of Effluents

4.1 Effects on Environment

The dairy industry is one of the most polluting of industries, not only in terms of the volume of effluent generated, but also in terms of its characteristics as well. It generates about 0.2–10 liters of effluent per liter of processed milk with an average generation of about 2.5 L of wastewater per liter of the milk processed. Dairy processing effluents are generated in an intermittent way and the flow rates of these effluents change significantly. The volume, concentration, and composition of the effluents arising in dairy industry are dependent on the type of product being processed, the production program, operating methods, design of the processing plant, the degree of water management being applied, and subsequently the amount of water being conserved. The sweet whey form the most polluting effluent by its biochemical composition rich in organic matter (lactose, protein, phosphorus, nitrates, nitrogen) and is from 60 to 80 times more polluting than domestic sewage.

The waste water of dairy contains large quantities of milk constituents such as casein, inorganic salts, besides detergents and sanitizers used for washing. All these components contribute largely towards their high biological oxygen demand (BOD) and chemical oxygen demand (COD). Which is much higher than the specified limits of Indian standard institute (ISI), now Bureau of Indian standard (BIS), for the discharge of industrial effluents; As these wastes are generally released to the nearby stream or land without any prior treatment, it is reported to cause serious pollution problems.

Dairy effluents decompose rapidly and deplete the dissolved oxygen level of the receiving streams immediately resulting in anaerobic conditions and release of strong foul odors due to nuisance conditions. The receiving water becomes breeding place for flies and mosquitoes carrying malaria and other dangerous diseases like dengue fever, yellow fever, chikungunya. It is also reported that higher concentration of dairy wastes are toxic to certain varieties of fish and algae. The casein precipitation from waste which decomposes further into a highly odorous black sludge at certain dilutions the dairy waste is found to be toxic to fish also. Dairy effluent contains soluble organics, suspended solids, trace organics. They decrease do, promote release of gases, cause taste and odor, impart color or turbidity, promote eutrophication.

The main environmental problems related to milk production affect the pollution of water, air and biodiversity. They often cause a growth of algae and bacteria that consume oxygen in the water and eventually suffocate the rivers leading to the gradual disappearance of fish. Hence, the need to treat dairy effluents by various processes is necessary (Deshpande et al. 2012).

4.2 Effects on Water

4.2.1 The Organic Components

The organic components of the wastewater from dairy processing operations can be classified as proteins, lactose and fat. These will affect the environment in different ways depending on their biodegradability and their solubility.

4.2.2 River Oxygen Levels and BOD

Fully aerated rivers at temperatures of 15–25 °C contain oxygen concentrations of at least 8 g/m^3. It is therefore essential that discharges to rivers maintain an oxygen concentration of at least 6 g/m^3. In order for this, the discharge to the river must not increase the river BOD by more than about 3 g m^{-3} (depending on the reaeration characteristics of the river). The organic components in dairy processing wastewater are highly biodegradable. In waterways, bacteria will consume the organic components of the waste. The process of biodegradation in waterways consumes oxygen according to Eq. 1.

$$\text{Organic Material} + O_2 \rightarrow CO_2 + H_2O + \text{Bacteria} \qquad (1)$$

4.2.3 Sewage Fungus

Low molecular weight organic compounds promote the growth of certain filamentous slimes in waterways. These bacterial colonies are collectively known as sewage fungus. The most common bacterial species in this category is *Sphaerotilus natans*. One of the major constituents of dairy factory wastewaters is lactose, a low molecular weight sugar that is known to promote sewage fungus growth. Sewage fungus growth has been related to lactose concentrations in rivers by Eq. 2 and this can be used to predict the extent of sewage fungus growth in a receiving waterway.

$$\text{Growth/g/m}^2 = 0.333 + 2.479\ \text{m(lactose)/g/m}^3 \quad (2)$$

4.2.4 Color and Turbidity

Wastewaters that are highly colored are likely to alter the color of receiving water. Dairy factory wastes probably contain little soluble color, although after various forms of treatment true color may result. Colloidal and particulate components in the waste reflect light back to an observer. This is known as apparent color. The concept of turbidity is closely related to this phenomenon. Milk wastes contain significant quantities of material that will result in turbidity of discharges.

4.2.5 The Inorganic Components (Mainly Nitrogen and Phosphorus)

One of the main aims of industry is to recover the protein (organic nitrogen component) of the waste and convert it to saleable products. Nitrogen is, therefore, a very important component of the dairy factory wastewaters. Some protein will be lost to the waste streams. Bacteria convert the nitrogen in proteins to the inorganic forms including ammonia, and the ammonium, nitrite and nitrate ions. Each of these inorganic forms of nitrogen has different environmental effects. Nitrate ions are toxic in high concentrations to both humans and livestock. In young infants, nitrate can be converted to the nitrite form, absorbed into the bloodstream and convert haemoglobin to methaemoglobin. Methaemoglobin cannot transport oxygen. The condition of methaemoglobinaemia affects infants less than six months in age because they lack the necessary enzyme to reconvert the methaemoglobin back to haemoglobin. To protect humans the usual limit placed on drinking water supplies is 10 g m^{-3} of nitrate-nitrogen.

Livestock can also suffer from methaemoglobinaemia. Since ruminants have a more neutral stomach pH and rumen bacteria that reduce nitrates to nitrite, deaths from methaemoglobinaemia can occur. This usually results from the consumption of nitrate rich feed; although a limit of 30 g m^{-3} nitrate-nitrogen on drinking water for stock has been suggested. Inorganic forms of nitrogen (nitrate, nitrite and ammonium ions) and inorganic phosphates act as plant nutrients in waterways. To protect receiving waters from undesirable growths it has been suggested that total inorganic nitrogen concentrations in receiving waters are limited to less than about 30–100 mg m^{-3} or that dissolved reactive phosphorus (inorganic phosphorus) concentrations are less than about 15–30 mg m^{-3}.

4.3 *Effects on Land*

Wastewater application to soils is a common method of waste treatment in the dairy industry.

4.3.1 Nutrients (Nitrogen and Phosphorus)

The major mechanisms for nutrient removal in soil based treatment systems are,

- Plant uptake and incorporation in animal products
- Adsorption and immobilization in the soil
- Losses to the atmosphere
- Losses to groundwater (leaching).

Plant uptake of nitrogen amounts to up to 500 kg/ha/year. For phosphorus, the amount is about 30 kg of phosphorus. If animals subsequently consume the pasture, up to 90 % of the nitrogen and phosphorus is recycled to the pasture. Losses of nitrogen to the atmosphere occur through volatilization of ammonia from urine and dung patches, and through the process of denitrification. Denitrification is the process where microorganisms reduce nitrate to either nitrous oxide or dinitrogen gas. This occurs under anoxic conditions (i.e. a lack of oxygen) and when a suitable organic carbon supply is available for energy. Denitrification rates can be quite high at wastewater irrigation sites. Losses of nitrogen (principally in the nitrate form) to groundwater can occur at some irrigation sites depending on the amounts of nitrogen removed by other means. The factor usually limiting the disposal of nitrogen containing wastes to soils is nitrate contamination of groundwaters that are subsequently used as water supplies for humans or stock. It is usual to apply normal drinking water guidelines under these circumstances. Phosphorus does not usually cause a problem by leaching to groundwater because of the high retention and immobilization of phosphates in soils.

4.3.2 Sodium and Other Minerals

Sodium, potassium, calcium and magnesium are all immobilized by soils and occupy cation exchange sites on soil colloids and clays.

4.4 *Effects on the Atmosphere*

4.4.1 Gaseous Emissions

Manufacturing operations can result in a number of emissions to the atmosphere. Boiler stacks result in emissions of carbon dioxide, sulphur oxides and nitrogen oxides to the atmosphere. Methane may be emitted from anaerobic waste treatment systems and nitrous oxide (N_2O) is emitted from the soil at wastewater irrigation sites. Carbon dioxide, methane and nitrous oxide are very important greenhouse gases, and it is likely that the consequences of these emissions will need to be considered in the future.

4.4.2 Dust/Odors

Particulate materials can be emitted from boiler stacks, powder driers, etc. Losses of particulate material may also occur from other factory processes. If particulate emissions are high then surrounding buildings are coated with dust and powder which, as well as being undesirable, can also be corrosive. Smoke and steam plumes from factories may also be regarded as a form of visual pollution. The emission of objectionable odors must be considered at industrial processing sites. Many waste treatment plants can produce undesirable odors (Onet 2010).

5 Wastewater Treatment

5.1 Need to Treat the Wastewater

Wastewater from dairies and cheese industries contain mainly organic and biodegradable materials that can disrupt aquatic and terrestrial ecosystems. Due to the high pollution load of dairy wastewater, the milk-processing industries discharging untreated/partially treated wastewater cause serious environmental problems. Hence, it is important to carry out a whey treatment as a starting point, in order to optimize a simple and economic method to treat the whole dairy effluent. Moreover, the Indian government has imposed very strict rules and regulations for the effluent discharge to protect the environment. The wastewater treatment which does not give any monetary benefit to dairy industry owners they release it directly to nearby water streams or on land (i.e. in nature) by giving only some of the primary treatment, due to lack of awareness in this regard and lack of funds.

As described previously, dairy processing wastewaters contain substantial quantities of organic matter, nitrogen and phosphorus. If excessive concentrations of these enter waterways, oxygen depletion and plant growth in the waterways may reach nuisance proportions. The manufacturing dairy industry uses two main methods of treating wastewater includes biological treatment in extended aeration systems and by spray irrigation to pasture (APHA 2005; Jaiprakash et al. 2011).

5.2 Pretreatment

Pretreatment in the dairy industry for many years meant some form of dampening flow, pH or organic load variations and a rudimentary fat/ solids tank. This is changing with the industry now installing pretreatment systems to reduce loadings on wastewater treatment systems and also to allow some factories to continue to discharge to municipal systems. Pretreatment systems are now being maximised to remove solid material using air flotation principles coupled with neutralisation of the wastewater and the addition of flocculants and polyelectrolytes. These systems, while removing solids and nutrients, are limited in their ability to reduce the organic loading in the wastewater because the main source of BODs in dairy plant wastewater is lactose which is soluble and hence cannot be removed by physical/ chemical means. The disposal of the recovered material can be of concern as environmental pressures increase and the solid material cannot safely be placed in landfills as it is still biologically active. Biologically active solids can be composted and utilized as a fertilizer. Work is being undertaken in New Zealand whereby the solid material is heated, the fat used in other processing industries and the remaining material, mainly protein, is being composted.

5.3 Land Treatment

Land treatment systems are used extensively in the New Zealand dairy industry. They use the soil as a biological medium to treat the components of the applied wastewater and hence they need to be designed to the appropriate criteria to ensure efficient operation.

5.4 Organic Loading

When wastewater is applied to pasture, soil microorganisms convert the organic matter present to carbon dioxide and water. During this process, biological slimes and additional bacteria are produced. On fine textured soils the production of slimes *etc*. can inhibit the movement of liquid through soil pores and lead to undesirable effects such as ponding. Dairy factory wastewaters can contain high concentrations of BOD primarily due to their lactose, fat and protein content. In the soil matrix, the normally soluble lactose is converted to bacteria. Some reports have shows an organic load of 2000 kg BOD per hectare is utilized over 16–20 days. Higher loadings can be used on some free draining soils. This application rate represents a design load of about 250 m^3 per hectare on each irrigation occasion.

The dairy industry uses aerobic or anaerobic treatment, or a combination of both, to treat the wastewater. Aerobic systems require an energy source to provide the oxygen required to assimilate the organic matter in the wastewater and hence are more suited to low to moderate strength wastewaters, since the higher the organic content the greater the oxygen demand and the greater the costs. Anaerobic systems have been developed for their ability to treat high strength wastes and the utilization of the methane gas. *Aerobic systems*: In aerobic treatment systems, bacteria, in the presence of oxygen, convert the organic components of the waste to carbon dioxide, water and bacterial biomass. All aerobic treatment systems have the potential to cause odors if operated incorrectly. The industry worldwide has tried many forms of aerobic treatment. These have included trickling filters, rotating biological contactors and various forms of mechanically aerated lagoon systems. In New Zealand only extended aeration activated sludge systems are used. Typical treatment parameters for an activated sludge plant treating dairy plant wastewater are 94 % COD, 99 % BOD5 70 % TKN and 50 % total phosphorus removal (Rana et al. 2011).

5.5 Anaerobic Treatment

Considerable experimental work has been undertaken on the anaerobic digestion of whey from casein and cheese plants. Various forms of high rate anaerobic digestion systems have been investigated with whey. However, few anaerobic systems treating whey have been installed, despite such systems being operationally viable and the value of methane produced from these systems as the industry values the components of the whey more highly. In an anaerobic digester, anaerobic bacteria, acting in the absence of oxygen, convert the organic components in the wastewater to methane, carbon dioxide and water (Javed et al. 2011). Organic forms of nitrogen are converted to the ammonium nitrogen form. Anaerobic digestion may be carried out in low rate lagoon systems or in high rate reactors. The more recent anaerobic digesters which have been installed in the dairy industry have been high rate digesters, usually with two stages to obtain better control of the anaerobic processes (Kolhe et al. 2009; Deshannavar et al. 2012). The advantages of anaerobic digestion are,

- Produce a valuable byproduct (methane), that can be recovered and utilized as a fuel
- Remove substantial quantities of BOD and COD without the input of mechanical energy for aeration
- Produce less sludge than aerobic systems.

5.6 Nutrient Removal

Dairy factory wastewaters contain substantial quantities of the plant nutrients nitrogen and phosphorus. If excessive concentrations of these enter waterways then they will promote the growth of plants in the waterways. Eventually these may grow to nuisance proportions. Wastewaters from dairy manufacturing are usually treated in either extended aeration activated sludge plants and discharged to suitable waterways, or are irrigated onto land after primary treatment. Activated sludge systems can remove some of the nitrogen and phosphorus in the waste sludge because these same nutrients are also required for bacterial growth. However, overall removals will, in some cases, be insufficient to meet environmental demands. Under these circumstances an alternative form of treatment or an add-on to the existing treatment will be required to meet discharge requirements (Tawfika et al. 2008).

6 Reduction of Air Emissions

The main emissions from boiler stacks are nitrogen oxides, sulphur oxides and particulates (ash and small quantities of solid fuel). Driers are extensively used by the dairy industry to dry a wide variety of milk powder products (Van-Oostrom and Cooper 1988). The main methods used to reduce atmospheric emissions in the dairy industry are,

- Cyclones and Multicyclones–Cyclones impart a swirl to combustion gasses, and separate heavier particles from the outside portion of the gas stream. These units are effective for larger particles.
- Baghouse Filters Bag–filters separate fine particles. Large surface areas are required.
- Electrostatic Precipitators–Strong electrostatic fields result in particles acquiring electric charges, and being attracted to, and precipitated on, large plate electrodes.
- Wet Scrubbers–Flue gas passes upwards through a chamber while water (with or without various additives) is sprayed down through the chamber, absorbing contaminants.

7 Conclusion

Dairy farms require some form of effluent management system. A range of site specific factors, such as herd size, proximity to creeks, gullies and underground aquifers, climate, soil type and availability of labour, should be considered when selecting the most appropriate system for a particular farm. In most situations, pond systems are more desirable than continuous application systems. However, well designed and managed continuous application systems may be quite acceptable and even more suitable than pond systems in some situations. They are generally better able to protect the environment, and enable farmers to make the most effective use of the nutrient and water value of the effluent.

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