

## DAIRY WASTEWATER: A REVIEW

### Abstract

The industries that produce a significant amount of effluents include food processing, textile pulp and paper, and distilleries . The dairy industry is a significant focus within the food processing sector due to its production of 0.2e10 liters of wastewater per liter of processed milk. The wastewater generated by the dairy industry is known for its elevated levels of biological oxygen demand (BOD), chemical oxygen demand (COD), and nutrients. In many instances, untreated wastewater is discharged into the environment, resulting in various significant issues. These include pollution of surface and groundwater, as well as eutrophication caused by the presence of nitrates and phosphates. These problems pose risks to human health and disrupt the balance of ecosystems.

**KeyWords:** Dairy industry effluent, Milk processing wastewater, Environmental effects, Physicochemical parameters, Organic load.

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## I. INTRODUCTION

Water is a fundamental component necessary for the maintenance of life and is highly regarded as a valuable asset owing to its extensive application across multiple domains, such as agriculture, industry, residential settings, recreational activities, and ecological preservation. The establishment of industries is driven by producing goods to cater to the needs of growing populations in developing nations. These sectors play a crucial role in facilitating and driving a nation's economic growth. Nevertheless, while engaging in the production of advantageous commodities, they concurrently generate waste and potentially perilous byproducts, thereby causing environmental pollution. Water contamination is commonly observed in processing industries, although pollution can also arise from the contamination of the air, soil, or water sources. The World Health Organization (WHO) provides a definition of water pollution as the adverse alteration of water resources due to the introduction of organic, inorganic, biological, or radioactive substances. This introduction of substances into water can lead to significant disruptions in the utilization of these resources or cause detrimental impacts [1].

Industrial wastewater commonly consists of two main types of waste: sanitary waste and process waste. Sanitary waste refers to the wastewater generated from human activities, such as toilets and sinks. Process waste, on the other hand, is produced during the various stages of production and includes wastewater from different sections, such as equipment and heating and cooling processes. Additionally, the wastewater generated from these industrial operations is often free from contamination. The presence of organic and inorganic constituents in wastewater can be identified as the underlying cause for the heightened concentrations of dissolved solids and biochemical oxygen demand (BOD) commonly observed [1,2].

The primary contributors of metallic substances in wastewater can be ascribed to a diverse range of industries, encompassing but not limited to chemical, distillery, sugar, food, dairy, paper and pulp, textile bleaching and dyeing, mining and quarries, battery manufacturing, nuclear power, organic chemical, leather/tannery, iron and steel, soap and detergent, electric power plant, metal refining, pesticides and biocide, petroleum and petrochemical, pharmaceutical, metal processing, and electroplating [3].

The process of industrialization plays a significant role in the economic development and expansion of a nation. Industrial pollution is a significant global issue, with the food industry being particularly noteworthy due to its substantial water consumption and high effluent production per unit of output [4].

The main aim of food processing industries is to enhance the availability of consumable goods by engaging in the processing of various raw materials, including fruits, vegetables, and milk. Each production batch requires a significant amount of water. Water is employed in many operational procedures, encompassing production, cleaning, sanitization, material transportation, and cooling [5].

## II. WASTEWATER CHARACTERIZATION IN THE FOOD PROCESSING SECTOR

Food waste constitutes a significant portion of municipal solid waste (MSW), and its disposal poses a notable environmental challenge in urban settings. The proportion of food waste within MSW exhibits variation across different countries, with Sweden reporting a fraction of 38%, Brazil ranging from 50% to 70%, and Turkey at 43%. Food waste (FW) is distinguished by its elevated levels of moisture and organic matter. Additionally, the perishable nature of food waste gives rise to odor-related challenges during its transportation [6].

The production of food waste encompasses the entire food life cycle, spanning from the agricultural phase to industrial manufacturing and processing, as well as retail and household stages [7]. The food processing sector comprises many industries, including but not limited to dairy, snacks, desserts, beverages, and distilleries. Numerous sectors generate wastewater due to a wide range of plant operations, including but not limited to production, cleaning, sanitization, cooling, and material transportation. However, it is worth noting that due to the significant presence of organic compounds in these wastewaters, their constituents are biodegradable and may not pose a significant hazard. Consequently, there is a subsequent increase in the levels of biological oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids (SS). Table 1 displays the characteristic features commonly observed in the food processing industry[5].

**Table 1: The Typical Characteristics of the Food Processing Industry**

Parameters	Standard in mg/L except pH
pH	5.5-9.0
Oil and grease	10
BOD (5 days at 25°C)	50
COD	250
TSS	50
TN	10
TP	2

TSS: Total suspended solid, TN: Total nitrogen, TP: Total Phosphorus,  
BOD: Biochemical oxygen demand, COD: Chemical oxygen demand

The wastewater generated from pea processing plants exhibited a chemical oxygen demand (COD) value of 5.8 mg/L, total solids (TS) concentration of 4.5 mg/L, and a volatile solids (VS) concentration of 3.8 mg/L. In contrast, the wastewater produced by carrot processing plants had a COD value of 7.7 mg/L, a TS concentration of 11 mg/L, and a VS concentration of 6 mg/L. In addition, the wastewater from celery processing plants exhibits a chemical oxygen demand (COD) of 1.4 mg/L, a total solids (TS) concentration of 1.7 mg/L, and a volatile solids (VS) concentration of 1.2 mg/L. On the other hand, leek wastewater has a COD of 4.1 mg/L, a TS concentration of 2.1 mg/L, and a VS concentration of 1.6 mg/L [8].

The wastewater generated from the production of vegetable ghee exhibited a pH value of 7.80, an electrical conductivity (EC) of 288, a concentration of total suspended solids (TSS) at 422 mg/L, and a concentration of total dissolved solids (TDS) at 288 mg/L. In contrast, the wastewater resulting from the production of the beverage displayed a pH value of 8.9, an electrical conductivity (EC) of 832, a concentration of total suspended solids (TSS) at 125 mg/L, a concentration of total dissolved solids (TDS) at 82 mg/L, and a biochemical oxygen demand (BOD) of 191 mg/L[9].

The physicochemical analysis of effluents generated during seafood processing was described by Thomas et al.[10]. The measurements were conducted for the following parameters: pH within the range of 6.8 to 7.5, total solids (TS) ranging from 2211.5 to 3779.9 mg/L, total suspended solids (TSS) ranging from 191.5 to 680.6 mg/L, biochemical oxygen demand (BOD) ranging from 964 to 2250 mg/L, and chemical oxygen demand (COD) ranging from 144 to 2700 mg/L.

The characterization of wastewater from the sugar industry was conducted by Lakdawala and Patel [11]. The analysis results indicate that the wastewater exhibits a pH value of 6.61, a chemical oxygen demand (COD) concentration of 1529.01 mg/L, and a biochemical oxygen demand (BOD) concentration of 910 mg/L. Bustillo-Lecompte et al. [12] carried out the characterization and treatment of wastewater from the slaughterhouse. The range of data for the characterization was recorded as pH 4.90–8.10, BOD 610–4635 mg/L, COD 1250–15,900 mg/L, TSS 300–2800 mg/L, TN 50–841 mg/L, and TP 25–200 mg/L.

### III. DAIRY INDUSTRY

The dairy industry is widely recognized as the primary source of food processing wastewater in many countries. Water is employed in multiple phases of the dairy industry, including but not limited to cleaning, sanitization, heating, cooling, and floor washing. Consequently, the industry's demand for water is substantial [13]. Typically, the dairy processing industry generates waste that is characterized by a notable abundance of organic substances, including proteins, carbohydrates, and lipids. These waste materials also exhibit elevated levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), as well as substantial concentrations of suspended solids and suspended oil grease. Each of these necessitates specialized interventions in order to prevent or mitigate environmental issues. Dairy wastewaters (DWs) display notable fluctuations in flow rates as a result of disruptions in the production cycles of diverse dairy commodities[14].

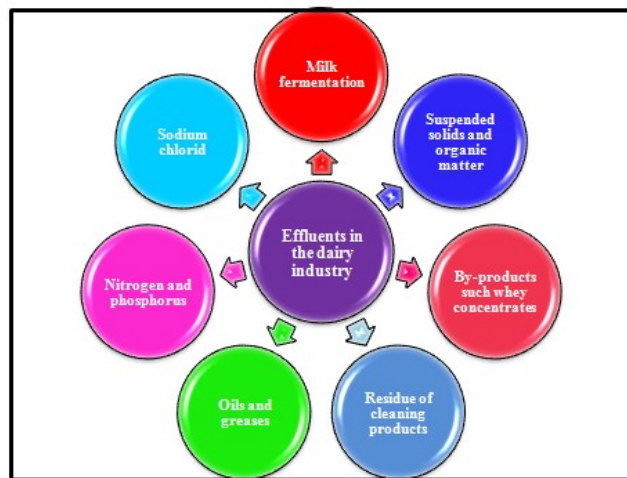
Water is of significant importance in the unit operations involved in milk processing. These operations encompass a range of activities such as cleaning, washing, sterilization, pasteurization, cooling, heating, and other essential processes that are necessary for the production of dairy products. As a result, the dairy industry requires a significant amount of water for the manufacturing of milk-based products, resulting in a proportional increase in the production of dairy wastewater. The water utilization within a dairy manufacturing facility leads to the production of effluent, which comprises approximately 50-80% of the overall water consumption. The wastewater in question consists primarily of sanitary wastewater, with the remaining 20-50% being comparatively less contaminated and suitable for various purposes such as equipment cleaning and irrigation. The quantity of wastewater generated by the dairy industry exceeds the volume of milk processed by approximately 2.5 times. The

composition of the effluent varies depending on the specific product and processing methods employed [15,16].

Annually, a substantial quantity of dairy waste, ranging from 4 to 11 million tons, is discharged into the global ecosystem, thereby presenting a significant threat to biodiversity. The discharge of untreated wastewater directly into the environment poses a significant issue, namely the reduction of dissolved oxygen levels. When fat effluents are present, a layer of oil and grease develops on the water's surface, impeding oxygen transfer. As a result, aquatic organisms and plants face challenging conditions for survival [17].

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are both higher in dairy wastewater, and there are also a lot of dissolved or suspended solids, like fats, oils, and grease, as well as nutrients like ammonia, minerals, and phosphates. Consequently, appropriate measures must be taken to address these constituents prior to disposal, as depicted in Figure 1 [18].

Moreover, it is worth noting that dairy industry wastewater often demonstrates significant fluctuations in pH levels. These variations primarily arise from the widespread utilization of acid and alkaline cleaners and sanitizers during the Cleaning-In-Place (CIP) procedures [19]. Using alkaline cleaners, specifically, can lead to elevated sodium levels in wastewater generated by the dairy industry [20]. The flow rates of wastewater in various factories exhibit significant variability, which can be attributed to factors such as the nature of the product being manufactured (with many factories involved in the production of diverse dairy products), the time of day (where increased wastewater generation is observed during cleaning operations), and the season (with higher volumes of milk received for processing typically occurring in the summer compared to the winter) [19,20]. The composition of carbohydrates, proteins, and fats, commonly referred to as FOG, in dairy wastewaters can vary significantly based on the specific dairy products manufactured by a facility and the operational techniques employed [21].



**Figure 1:** Typical Parameters Found in Effluents from the Dairy Industry [18]

Table 2 displays the reported COD values for various dairy products. The disposal of any of these products may contribute to an elevation in the concentration of pollutants in the dairy factory wastewater, potentially leading to an increase in its overall strength. The implementation of waste minimization strategies during production can significantly reduce the organic load of the wastewater that needs to be treated [1].

**Table 2 Chemical-Oxygen-Demand (COD) Values for Dairy Products and Domestic Sewage.**

Dairy product	COD (mg L <sup>-1</sup> )	References
Milk	147,000	[22]
	150,000	[19]
	190,000	[23]
	210,000	[24]
Skim milk	100,000	[24]
	120,000	[23]
Evaporated or condensed milk	364,790	[19]
	378,000	[25]
Milk powder	950,000	[25]
Whey powder	929,000	[25]
Whey	80,000	[23]
	75,000	[24]
Cream (30%)	860,000	[23]
	860,000	[24]
	750,000	[25]
Yogurt whey	41 019-42 943	[1]
Buttermilk	94 866	[26]
Domestic sewage	500	[23]
	500	[24]

The implementation of effective CIP management practices, such as the retrieval of the final rinse water and the adoption of burst rinsing instead of continuous rinsing during the cleaning process of yogurt vats, has the potential to decrease water consumption. In order to decrease the organic content of wastewater, several strategies can be employed. For instance, the collection and treatment of dry ingredient spillages as solid waste can be implemented. Additionally, extending the drainage times of yogurt vats and pipes can be effective. Moreover, the deposition of heat, particularly during the heating process of sweetened yogurt, can be minimized by adopting a more gradual heating approach [27].

Milk that has been pasteurized and sterilized, yogurt, ayran, strained yogurt (concentrated yoghurt), cheese, cream, butter, ice cream, and milk powder are just a few of the goods that are available from the dairy sector. Both the manufacturing of goods and the operation of packing facilities contribute to the creation of waste water. Wastewater can be found in both of these processes. When considering the issue of environmental pollution, the crucial factor is not solely the quantity of water utilized but rather the specific composition and concentration of the waste substances present in the water[1,2].

- The packaging unit produces wastewater while cleaning bottles, jars, containers, and other packaging-related equipment.
- In order to successfully produce butter, the facility that produces cream makes use of both sweet cream and sour cream in the process. The separation of cream from milk is accomplished by using the technique of centrifugation. The milk that has been skimmed of its cream is used for the necessary processes, while the remaining cream is churned into butter. The butter is then stored in the refrigerator. The act of washing surfaces and cleaning items results in the production of waste water as a byproduct of the operation.
- There are many steps involved in the process of manufacturing cheese. The process of creating cheese consists of several phases, including coagulating the milk, cutting the curd, cooking it, draining it, inserting the curd in cheese molds, and pressing the molds. Molds are used to give the cheese its shape before it is packaged. The majority of the state's wastewater comes from the processing of whey. However, the majority of whey can be reused if it is dried first. Because of this, rather than being discharged into the environment as wastewater, it is repurposed in the manufacturing process of ready-made delicacies such as cookies and chocolates.
- In the ice cream manufacturing facility, a mixture of milk, additives, sugar, and thickeners is combined. Following the pasteurization and subsequent chilling processes, aromas are added and then packaged. Wastewater containing detergents and disinfectants is produced as a result of the facility's cleansing and disinfecting procedures.
- In the process of producing condensed milk, milk that has been heated is subjected to evaporation and homogenization, resulting in the production of milk that is devoid of sugar. This process is also used to produce sweetened condensed milk. During the production of milk powder, vacuum evaporation and spray dehydration are employed.
- The purpose of straining yogurt is to decrease its water content by eliminating the serum phase, thereby enhancing the product's ability to resist deterioration. The whey derived from the production of strained yogurt is typically disposed of through the sewer system and lacks commercial value. The presence of organic and inorganic matter in this whey leads to both environmental pollution and nutrient losses. In the manufacturing process of strained yogurt, it has been observed that around 33% of the yogurt is retained within the bag, while the remaining 67% is expelled as serum.

**1. Dairy Industry Waste Sources And Waste Potential:** The composition of the effluents produced in a dairy facility is subject to multiple factors, such as the nature of the product being processed, the scheduling of production, operational procedures, the architectural layout of the processing plant, the degree of water management employed, and the implementation of water conservation strategies. The dairy industry has undergone substantial growth in various countries as a result of increasing consumer demand for milk and milk-derived products. The processing of dairy products leads to a significant quantity of waste, primarily in the form of chemically altered liquid, and necessitates a substantial water consumption. According to Sarkar et al. [13], water is utilized in all stages of the processing. As a result, there has been a significant increase in the discharge of wastewater derived from the dairy sector. The dairy industry generates an estimated 6–10liters of wastewater for every liter of milk that is processed. Dairy wastewater may be divided into three major categories[28]:

- Processing waters are defined as the water that is employed in diverse cooling and heating procedures. In general, these waste streams are characterized by a lack of contaminants and can be either recycled or released into the stormwater system with minimal processing. The storm water system is primarily designed for rain water runoff. Processing water refers to polluted water that is created during the cooling of milk in coolers and condensers, as well as from the condensates produced during milk or whey evaporations [15]. In addition, the process of drying milk and whey results in the production of vapors. According to Tikariha and Sahu[29], dairy effluents are generally considered to be very clean. However, there may still be some milk or whey droplets, as well as volatile substances from evaporators, present in the effluent. When processing water, pollutants are not present. As a result, it can be discharged with stormwater or reused to supplement the water supply for milk processing, with only minimal pretreatment required [30]. The reuse of treated wastewater is possible in facilities that do not directly interact with the final products. It can be used for hot water and steam production, as well as for cleaning the membrane used in milk clarification and separating valuable components from milk and/or dairy byproducts. Additionally, the water that is generated from the cooling process during pasteurization can be effectively utilized for various purposes, such as room cleaning, lawn irrigation, and more[31].
- Cleaning wastewater: The generation of wastewater for cleaning purposes primarily stems from the cleaning of equipment that has been in contact with milk or milk products, unintended spills of milk and milk products, whey, pressings, and brines, secondary cheese whey, yogurt whey, buttermilk, cleaning-in-place (CIP) procedures, and water resulting from equipment malfunctions and operational errors. The wastewater stream may potentially contain a range of substances, such as milk, cheese, whey, cream, and separator and clarifier dairy waters [32]. Additionally, it may also contain diluted yogurt, starter culture, diluted fruit and stabilizing compounds [33]. The generation of wastewater occurs during the process of cleaning equipment that comes into direct contact with milk and/or dairy products[15]. The process of cleaning wastewater involves the removal of spillage products. According to Kolhe et al. [34], the substances of interest in this study include milk, brine, whey and clean in place (CIP) wastes, as well as discharges resulting from equipment malfunctions and operational errors. According to Slavov[15], a significant proportion exceeding 90% of the organic solids found in dairy effluent can be attributed to various sources, including milk and manufacturing by-products such as cheese fragments, cream, whey, water derived from the separation and clarification processes involving suspended solids and color, starter cultures, yogurt, fruit concentrates, and stabilizers. Hence, it is imperative to administer suitable treatment to effectively address the moderate pollution levels in the cleaning water before it is either reused or disposed of.
- Sanitary wastewater is commonly transported via pipelines for direct conveyance to a sewage treatment facility. The presence of sanitary wastewater in dairy wastewater is attributed to the utilization of lavatories, shower rooms, and other similar facilities by staff and workers. The chemical composition of sanitary wastewater exhibits similarities to that of municipal wastewater and is subsequently discharged directly into the sewerage system [15, 31]. Kolhe et al. [34] have suggested that in situations where dairy effluents are imbalanced prior to undergoing secondary aerobic



treatment, it is feasible to employ sanitary wastewater as a nitrogen source. A subsequent section provides a more comprehensive analysis of the different procedures employed in the dairy industry, along with the corresponding volumes and properties of the wastewater generated.

Dairy wastewater and liquid waste are generated by multiple sectors within the dairy industry, encompassing cheese and butter plants, ice cream plants, condensed milk plants, and facilities engaged in the reception and bottling processes [28]. The cheese production process involves the generation of varying and significant volumes of wastewater. The initial stage entails the manufacturing of curd. The separation of curd from whey is achieved through mechanical processes, which are then followed by the subsequent drying of the curd. Afterward, salt is added to the curd and subjected to a pressing procedure to eliminate excess moisture. In the final analysis, the cheese is meticulously encased. During this process, a significant volume of wastewater is generated, presenting the option of either disposal or repurposing to produce alternative cheese varieties. Cream is the principal raw material employed in the production process of butter. During the manufacturing process, the cream is subjected to centrifugation to facilitate the separation of its components, specifically butter, and buttermilk. The buttermilk is subsequently discharged as wastewater[35, 36].

Similarly, a significant volume of wastewater is produced during yogurt and ice cream manufacturing. Water is employed in the bottling and receiving departments to cleanse containers and facilitate sterilization procedures. The concluding portion of the analysis focuses on the category of sanitary wastewater directly associated with sewage. The generation of wastewater occurs due to diverse processes, including the manipulation of milk containers, the washing procedure, the conversion of curd into butter, the production of cheese, the disposal of spoiled milk, and the inadvertent release of water and milk from pipelines. Furthermore, cleaning floors and dairy equipment necessitates using cleaning agents that produce both organic and inorganic waste, along with the presence of nitrogen and chlorine[35, 36].

- 2. Characteristics of Dairy Wastewater In Milk Processing:** The dairy industry utilizes many carbohydrates and proteins in manufacturing and washing processes. Consequently, the wastewater generated from these sectors contains elevated levels of nitrogen fixation and other intricate organic substances Dairy wastewater is characterized by the absence of highly toxic chemical substances commonly found in other industrial effluents[37]. However, it primarily consists of a combination of organic compounds, including lactose, whey proteins, nutrients, and fats. This composition emits unpleasant odors and causes discomfort to the surrounding population during the degradation process [13]. The characteristics of dairy effluents are influenced by various factors, including the scale of the industrial operation, the specific processing methods employed, the type and efficiency of the treatment method used, the parameters of the process, the type of operation being conducted, the choice of equipment for cleaning, the type of waste being discharged, and the associated costs of wastewater treatment [38]. The dairy industry plays a significant role in generating substantial quantities of industrial wastewater that contains a high organic load, posing challenges for effective elimination [39]. The

chemical composition of certain dairy effluents is outlined in Table 3[40]and composition of milk processing effluents is showed in Table 4 [1, 15].

**Table.3.Physical and chemical parameters of dairy effluent**

Physical parameters and chemical parametres	Value
Color and apperance	Dirty White-Greyish and turbid
Odour	Punget
Temperature	20-25 <sup>0</sup> C
pH	6.2-7.2
Total solid	2400 mg/L
Total Dissolved Solids	2300 mg/L
Total Suspended Solids	1000mg/L
COD	2880-8000 mg/L
Oil and Grase	320 mg/L
Phosphorous content	11.7 mg/L
Total sugar	29 µg/L
Total protein	1600 µg/L
Total organic conten(TOC)	540-2240 µg/L

**Table 4. Composition of milk processing effluents [1, 15]**

Milk processing effluent	pH	BOD <sub>5</sub>	COD	FOG	TS	TSS	TN	TP
Mixed dairy	4-11	0,24-5,9	0.5-10.4	0.02-1.92	0.71-7	0.06-5.80	0.01-0.66	0-0.6
Milk reception	7.19	0.8	2.54	1.06	-	0.65	-	-
Dairy sewage	9.1	1.08-2.81	2.04-4.73	0.24-0.29	-	0.53-1.13	-	0.02-0.03
Fluid Milk	5-9.5	0.5-1.3	0.95-2.4	-	-	0.09-0.45	-	-
Yoghurt	4.53	-	6.5	-	-	-	-	-
Butter	12.08	0.22-2.65	8.93	2.88	-	0.7-5.07	-	-
Ice cream	5.1-6.96	2.45	5.2	-	3.9	3.1	-	0.014
Cheese	3.38-9.5	0.59-5	1.65-3	0.33-2.6	1.92-53.2	0.19-2.5	0.018-0.83	0.005-0.28
Cheese whey	3.92-6.5	27-60	50-102.1	0.9-14	55-70.9	1.27-22.15	0.2-1.76	0.12-0.53
Cheese whey wastewater	4.6	35	-	0.8	-	-	-	0.64
Yogurt whey	4.34	-	41 019	10 551	5.56	1 016-1 293	-	29.70
Whey processing effluent	5-9	0.59-1.21	1.07-2.18	-	-	0.08-0.44	-	-
Washing waste water	10.37	3.47	14.64	3.11	-	3.82	-	-

BOD<sub>5</sub>: biological oxygen demand for 5 days, COD: chemical oxigene demand, FOG: fat, oil and grase, TS: total solid, TSS:total suspended solids, TN: total nitrogen, TP:total phosphorus

According to Shete and Shinkar [30], dairy wastewater typically exhibits a white or yellow hue. The temperature of the water plays a crucial role in influencing the abundance of phytoplankton. The discharge of water from the dairy industry, characterized by elevated temperatures, has adverse effects on the surrounding land. The operational procedures are outlined as follows:

- **Milk Reception and Storage Areas:** This waste can arise from overflow, defective hose connections, pipeline leaks, and insufficient drainage of milk transport vehicles and storage tanks before initiating the Cleaning-in-Place (CIP) process. The wastewater in this particular region primarily comprises various constituents found in whole milk, including milk fat, protein, and lactose. To mitigate pollution loads, it is recommended to implement several measures. These include ensuring the appropriate drainage of tanker trucks and storage tanks, employing properly connected and securely fastened hoses, installing self-draining pipes at a slight incline, incorporating level controls in storage tanks to prevent overflow incidents, and adopting well-suited cleaning-in-place (CIP) processes for tanker trucks and storage tanks. Notably, reusing final rinse water from cleaning operations for the initial rinse of subsequent cleaning processes can further reduce pollution [25, 41].
- **Heat Processing of Milk:** The generation of wastewater during the pasteurization and sterilization processes of liquid milk and cream primarily stems from the cleaning activities of heat exchangers. These heat exchangers are responsible for most organic contaminants in the cleaning water, which accumulate at the interfaces between the product and water. The wastewater produced in this region primarily consists of various constituents found in whole milk, including milk fat, milk protein, and lactose [25]
- **Production of Evaporated Milk Products:** The manufacturing process for sterilized unsweetened evaporated milk and sweetened condensed milk entails the concentration of pasteurized milk in evaporators, followed by applying heat treatment to the product either before or after packaging. The sole distinction observed in the sweetened condensed milk manufacturing process lies in including sugar in the evaporated milk immediately following the evaporation stage [24,25].The organic loads of wastewater produced during these processes are primarily determined by the quantity of milk that is flushed from the processing equipment at the beginning and end of production, as well as the quantity of organic and inorganic compound deposits that are formed due to the heating processes during milk evaporation and subsequently eliminated through cleaning [25].
- **Production of Powdered Dairy Products:** The manufacturing process for powdered dairy products, such as milk and whey powders, consists of two main steps. Initially, liquid pasteurized milk, or whey, is concentrated through evaporation. Subsequently, the concentrated products undergo spray drying. Milk powder production typically involves several steps following pasteurization. Before evaporating and drying the

whey, it is necessary to recover casein fines and milk fat. Subsequently, the whey should undergo thermalization before undergoing concentration and drying processes. The wastewater from milk powder production primarily consists of protein, lactose, and fat [24,25]. In contrast, the wastewater from whey powder production contains whey proteins, lactose, casein fines, and fat milk losses resulting from whey separation. Most wastewater is typically produced during the initiation and cessation of evaporation and drying procedures and during cleaning activities. To minimize the organic load of wastewater, it is advisable to ensure that evaporators are emptied correctly before the cleaning-in-place (CIP) process begins and between each CIP step. It is recommended to properly dispose of dry products resulting from product spillages and the cleaning of spray towers as solid waste. The condensate produced during evaporation processes has potential applications in cooling systems or as a source for boiler feedwater [25, 41].

- **Cheese Manufacture:** Most of the wastewater in this area is produced during equipment flushing at the conclusion of a processing cycle, as well as during Cleaning-in-Place (CIP) procedures. Wastewater commonly consists of constituents such as milk, milk fat, brine, whey, and cheese fines. The discharge of starter milk, whey, and curd fragments during cheese production processes may substantially impact the organic content of wastewater. The implementation of optimal curd-cutting techniques would result in a significant reduction in both milk fat and cheese fines content in whey. Whey collection should be done judiciously, and its utilization should primarily be focused on commercial applications. According to Hale et al. [25] and Tetra Pak [41], it is recommended to gather curd spillages before cleaning factory floors and to dispose of them as solid waste appropriately.
- **Butter Manufacture:** Most of the wastewater in this area is produced through the flushing of residual product from equipment and floors, the hosing down of equipment after production, and the implementation of cleaning-in-place (CIP) operations—the adhesion properties of butter result in its tendency to adhere to surfaces. Consequently, the wastewater produced in this context would predominantly consist of cream and butter constituents, including buttermilk and elevated milk fat levels. A potential strategy to decrease the quantity of cream and butter entering cleaning wastewater is to manually remove these substances from accessible production surfaces before the commencement of the cleaning process. [25,41]
- **Yoghurt Manufacture:** Wastewater is produced as a result of the cleaning procedures employed for various production equipment, including fermentation vats, heat exchangers, and storage vessels for ingredients. According to Tamime and Robinson [27] and Hale et al. [25], the wastewater commonly consists of yogurt with low concentrations, milk fat, residual heat from heat exchangers, fragments of fruit and diluted fruit preserves, diluted sugars (including lactose), stabilizers, and flavor compounds. [24,27] The substantial viscosity of yogurt plays a significant role in increasing the organic load present in cleaning waters, as it has a tendency to adhere to surfaces involved in production. The presence of milk powder spillages, which contain approximately 9.5 times more milk solids than liquid milk, as well as fruit concentrates with chemical oxygen demand (COD) loads equal to or exceeding 500 g mL<sup>-1</sup>, can contribute to an elevated organic load [25].

- 3. Composition And Characteristics Of Dairy Industrial Waste:** The dairy industry has experienced significant expansion due to the global population, economic advancements, and technological advancements [42]. According to Slavov [15], raw milk undergoes processing to produce a range of dairy products, including pasteurized milk, yogurt, cheese, cream, butter, milk, and whey powder. According to a Food and Agriculture Organization (FAO) report, global milk production reached 852 million tonnes in 2019. The FAO further projected that this figure will increase to 997 million tonnes by 2029, with an annual growth rate of 1.6% [43]. The dairy industry produces a significant amount of wastewater, ranging from 2.5 to 10 liters per liter of product. This is primarily due to material loss, which accounts for 0.1% to 1.9% of the wastewater, as well as the rinsing, cooling, and sanitizing processes involved in dairy production. Hence, the dairy industry faces a significant challenge in effectively and environmentally responsibly managing wastewater through sustainable, low-carbon methods [43,44,45].

The waste generated by food industries, such as the dairy industry, is characterized by elevated concentrations of organic matter, oil and grease, fatty acids, and significant amounts of nitrogenous compounds [46]. Dairy wastewater typically exhibits elevated dissolved organic constituents, including lactose, minerals, fat, and whey protein. The composition of raw dairy wastewater exhibits significant variation, primarily due to the specific products and operations involved [47]. Furthermore, alongside the detergents and sanitizers employed for washing, the wastewater in question also encompasses substantial quantities of milk components, such as casein, inorganic salts, and lactose. Singh et al. [48] have identified the presence of casein, fat, lactose, valuable nitrogen, phosphorus, potassium, and organic matter in dairy sludge. Whey, a prominent by-product of the dairy industry, is generated due to the manufacturing processes involved in cheese and casein production. Milk whey has various constituents, including lipids, carbohydrates, soluble vitamins, minerals, and proteins. According to a study by De Jesus et al. [49], approximately 75% of the total whey solids consist of lactose. Sediment waste derived from the dairy industry is a by-product that arises during clarified ghee or butter production. This waste consists of fats (fatty acids) and proteins.

The initial characterization of dairy wastewater was conducted to determine the specific anaerobic treatment requirements. The composition of dairy wastewater is subject to variation based on factors such as the specific product being manufactured, seasonal fluctuations such as summer and winter, the production cycle of the products, and the utilization of various additives and cleaning agents [44]. In summary, the composition of the substance typically encompasses a broad pH range (3.3–12.0), a significant amount of organic matter (chemical oxygen demand (COD)=0.7–92.8 g/L), which includes carbohydrates (5.4–62.9 g/L), dairy proteins (casein/whey: 1.3–13.1 g/L), lipids (0.07–39 g/L), and varying concentrations of total suspended solids (0.1–23 g/L, with over 72% being organic). Due to the considerable variation in composition, the processing of dairy wastewater poses significant challenges. Furthermore, the wastewater exhibits considerable fluctuations in the concentrations of calcium (ranging from 1.4 to 960 mg/L), sodium (ranging from 84 to 2325 mg/L), potassium (ranging from 8 to 690 mg/L), and phosphorus (ranging from 29 to 1099 mg/L). However, it is characterized by low levels of iron (ranging from 0.03 to 6.7 mg/L), cobalt (ranging from 0.001 to 0.022 mg/L), and nickel (ranging from 0.004 to 1 mg/L) [19, 50,51].

In the context of dairy effluents, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are important. The biochemical oxygen demand (BOD) in untreated effluents exhibits a range of 0.8 to 2.5 kilograms per metric ton ( $\text{kg t}^{-1}$ ) of milk. Comparatively, the chemical oxygen demand (COD) typically registers 1.5 times the BOD level. The concentration of total suspended solids varies between 100 and 1000 milligrams per liter, while nitrogen is also present at approximately 6% of the biochemical oxygen demand. Additionally, the effluent may contain phosphorus within a range of 10-100 mg L<sup>-1</sup>. The primary contributors to biochemical oxygen demand (BOD) in wastewater are cheese, butter, cream, and whey production processes. The waste load equivalents for various milk constituents are as follows: 1 kilogram of lactose is equivalent to 1.13 kilograms of chemical oxygen demand (COD), 1 kilogram of milk fat is approximately equivalent to 3 kilograms of COD, and 1 kilogram of protein is equivalent to 1.36 kilograms of COD. Nevertheless, it is essential to note that the characteristics of these effluents may exhibit variations across different industries [52].

Total Soluble Solids (TSS) is a critical parameter commonly employed to assess and ascertain the efficacy of wastewater treatment processes. Researchers have reported a high concentration of total suspended solids (TSS) in effluent from dairy milk [46,53].

In a recent study by Al-Wasify et al. [53], an assessment was made of the physicochemical parameters of the effluents from the dairy industry. The findings revealed the presence of elevated pollution parameters in the wastewater. The researchers discovered that the mean temperature of the effluent was measured to be 34 °C, the total dissolved solids concentration was 1222 mg L<sup>-1</sup>, and the pH level was determined to be 9.8. In addition, the concentrations of dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were measured to be 1.2 mg L<sup>-1</sup>, 650 mg L<sup>-1</sup>, and 1448 mg L<sup>-1</sup>, respectively. A separate study examined the physicochemical characteristics of dairy effluents collected during January and July 2011. In the study conducted by Verma and Singh [54], it was observed that the values of temperature, pH, BOD, and COD exhibited variations between January and July. The temperature in January was recorded as  $27 \pm 2.08$  °C, while in July, it was  $31 \pm 1.53$  °C. The pH values were  $6.8 \pm 0.64$  in January and  $6 \pm 0.69$  in July. Similarly, the BOD levels were measured as  $320 \pm 26.76$  mg L<sup>-1</sup> in January and  $355 \pm 78.99$  mg L<sup>-1</sup> in July. Lastly, the COD concentrations were determined as  $954 \pm 86.18$  mg L<sup>-1</sup> in January and  $982 \pm 67.57$  mg L<sup>-1</sup> in July. This study's findings demonstrate variations in the physicochemical parameters of dairy effluents across different dairy industries and seasons.

Tikariha and Sahu [55] undertook a study focused on the characterization and treatment of wastewater originating from the dairy industry. The wastewater samples were collected at monthly intervals over the course of one year. The analysis yielded the subsequent findings: pH levels ranging from 6.1 to 7.7, electrical conductivity (EC) values ranging from 352.7 to 954.0  $\mu\text{mhos/cm}$ , biochemical oxygen demand (BOD) concentration of 9033 mg/L, chemical oxygen demand (COD) concentration of 4958 mg/L, and total phosphorus (TP) concentration ranging from 18 to 26.42 mg/L. In 2015, Dubey and Joshi conducted a comprehensive analysis and remediation of wastewater originating from the ice cream industry [23]. The observed parameters include a pH range of 6.96–7.95, a COD concentration ranging from 1,600 to 3,200 mg/L, a BOD

concentration of 1800 mg/L, TS concentrations ranging from 3788 to 3800 mg/L, and TSS concentrations ranging from 1158 to 1183 mg/L.

#### **IV. ENVIRONMENTAL IMPACTS FROM THE DISCHARGE OF DAIRY WASTEWATER**

The effluents the dairy industry generates exhibit a high degree of concentration, with the organic load primarily attributed to the presence of carbohydrates, proteins, and fats derived from milk. The high concentration of organic matter in the dairy waste stream may give rise to significant challenges regarding the organic load, particularly within the local municipal sewage system. The dairy industry is responsible for pollution that adversely affects air, soil, and water [56]. Moreover, this phenomenon may be attributed to the occurrence of climatic fluctuations. The rapid degradation of effluents from dairy waste upon discharge into water reservoirs, caused by the high organic load, leads to a depletion of dissolved oxygen (DO) levels. Water bodies in this region serve as breeding grounds for various hazardous diseases such as Malaria, dengue, yellow fever, and chicken guinea while facilitating the proliferation of disease-carrying insects like mosquitoes and flies [53]. In addition, the authors [57] highlight that these factors pose various operational challenges to the biological treatment units. These challenges include reduced sludge settleability, oxygen depletion, and decreased process efficiency. Raw milk contains ammonia, nitrate, and nitrogen, which have the potential to induce methemoglobinemia. Additionally, when converted into nitrite, these substances can contaminate groundwater [58].

A high concentration of dairy waste can have toxic effects on certain species of fish and algae [30]. Dairy effluent discharge leads to the proliferation of algae and bacteria, depleting the oxygen levels in water bodies and causing asphyxiation in the river ecosystem. The aforementioned process results in the gradual evolution of aquatic organisms [30]. Elevated total suspended solids (TSS) levels can pose challenges for aquatic organisms. The presence of suspended particles in receiving water bodies can potentially restrict the penetration of light, leading to the possibility of fish gill clogging. The primary sources of suspended solids are gelatinous milk and flavorings [53].

Whey is the primary contaminant in milk processing wastewater, attributed to its elevated organic and volumetric loads. Whey comprises carbohydrates, with lactose being the primary constituent, accounting for approximately 4-5% of its composition [15]. Lactose is regarded as the most environmentally detrimental by-product due to its high levels of biochemical oxygen demand (BOD) exceeding 35,000 mg L<sup>-1</sup> and chemical oxygen demand (COD) surpassing 60,000 mg L<sup>-1</sup>. If left untreated, the disposal of this industrial effluent has the potential to modify the physical and chemical properties of soil, leading to a reduction in crop productivity and a decrease in the availability of oxygen in water [49]

The disposal of milk whey in rivers and lakes has been identified as a significant source of pollution due to the high levels of biochemical oxygen demand (BOD) (40–48,000 mg L<sup>-1</sup>) and chemical oxygen demand (COD) (89–95,000 mg L<sup>-1</sup>) found in this by-product, as well as the substantial quantities of phosphorus and nitrogen it contains [59]. These conditions lead to an increase in the eutrophication process, which causes an overgrowth of microorganisms and aquatic plants. Based on an estimation provided by De

Jesus et al. [49], it was determined that approximately 40,000 L of untreated milk whey resulted in a contamination level equivalent to the output of 250,000 individuals. The primary cause of pollution from industrial activities is wastewater discharge, which has a significant impact on the surrounding ecosystem. The deleterious impact of industrial waste manifests in living organisms and agricultural practices, leading to environmental degradation [59].

The dairy industry is recognized as one of the most environmentally detrimental sectors due to its significant effluent production and the quality of the effluent itself. The industry generates approximately 0.2-10 liters of effluent per liter of processed milk, with an average of 2.5 liters of wastewater per liter of milk processed. Dairy processing effluents are generated intermittently, resulting in fluctuating flow rates. These effluents' origin concentration, and composition are contingent upon various factors, including the specific product being processed, the production schedule, operational practices, plant design, water management strategies, and the extent of water conservation measures implemented. The waste generated by dairy industries encompasses diverse types, such as wastewater from the production line (including equipment and pipe cleaning), cooling water, domestic wastewater, buttermilk, acid whey, and sweet whey[2, 30].

The biochemical composition of sweet whey, which is abundant in organic matter such as lactose, protein, phosphorus, nitrates, and nitrogen, renders it the most environmentally detrimental effluent. In fact, sweet whey is estimated to be 60 to 80 times more polluting than domestic sewage. The waste water generated from dairy operations contains significant amounts of milk components, including casein and inorganic salts, as well as detergents and sanitizers utilized during the cleaning process. These various components significantly contribute to the elevated levels of biological oxygen demand (BOD) and chemical oxygen demand (COD). The discharge of industrial effluents, that exceed the prescribed limits set by the Indian Standard Institute (ISI), now known as the Bureau of Indian Standard (BIS), has been observed to result in significant pollution issues. These effluents are typically released into nearby streams or land without undergoing any form of pre-treatment[30].

Dairy effluents undergo rapid decomposition, leading to a swift depletion of dissolved oxygen levels in the receiving streams. This depletion promptly creates anaerobic conditions and subsequently gives rise to the release of highly unpleasant odors, thereby causing nuisance conditions. The accumulation of water in the receiving environment, which serves as a breeding ground for these vectors, facilitates the presence of flies and mosquitoes carrying diseases like malaria, dengue fever, yellow fever, and chicken guniya. According to reports, an elevated concentration of dairy waste has been found to exhibit toxicity towards specific species of fish and algae. The precipitation of casein from waste material, upon decomposition, results in the formation of a black sludge with a strong odor. It has been observed that at specific dilutions, this sludge derived from dairy waste exhibits toxicity towards fish. Dairy effluent is comprised of soluble organic compounds, suspended solid particles, and trace amounts of organic substances. These factors result in a decrease in dissolved oxygen levels, facilitate the emission of gases, induce changes in taste and odor, introduce color or turbidity, and contribute to the process of eutrophication[2, 30].

The primary environmental concerns associated with milk production pertain to the contamination of water, air, and biodiversity. The proliferation of algae and bacteria



frequently induces oxygen depletion in water bodies, resulting in the asphyxiation of rivers and a subsequent decline in fish populations. Therefore, it is imperative to employ diverse methodologies for the treatment of dairy effluents [15,30].

## V. REDUCING THE QUANTITY OF POLLUTANTS IN DAIRY WASTE WATER

There are several methods available to decrease the amount of contaminants present in dairy wastewater. There are several effective methods for reducing contaminants in wastewater. These include implementing closed systems, reusing water, and recirculating products and water mixtures through membrane filters. Dairy factories frequently use ultrafiltration and microfiltration to effectively clean and recycle CIP solutions. Using condensation water from evaporators for other purposes within the plant is a more favorable option. The constant need to control and prevent product and water waste in the processing plant is essential. By reading the water meter and monitoring daily usage, you can uncover hidden water losses in the subfloor and subterranean pipework [41].

The daily water consumption should be compared to the daily milk processing amount. The graph should display the water consumption, measured in cubic meters per tonne of processed milk, and it should be easily accessible. The average water-to-milk ratio is typically 2.0:1. However, with effective water conservation practices, it is possible to reduce the ratio to less than 1:1.[41]. The following general suggestions can serve as a helpful guide for minimizing water and product waste:

### 1. General Milk Treatment

- In the process of receiving milk, specifically during the emptying of tankers, it is crucial to maintain a minimum vertical distance of 0.5 m between the outlet of the tankers and the receiving container or tank. Additionally, it is essential to ensure that the connecting hose is adequately stretched to facilitate the complete drainage of the tankers.
- Proper identification and labeling of pipelines is essential to prevent the mixing of goods or potential leakage due to incorrect connections.
- During the installation process of pipelines, it is imperative to arrange them in a manner that incorporates a carefully calculated and slight slope. This slope is necessary to facilitate self-drainage. To mitigate the risk of vibration-induced loosening of couplings and subsequent leakage, it is imperative to ensure the pipes are firmly anchored.
- Level controls are implemented to mitigate the risk of overflow in all tanks. The cessation of the feeding pump occurs when the maximum level is attained, triggering an alert for the plant operator. Alternatively, an automated valve system may redirect the product to an alternate tank.
- It is more advantageous to proactively minimize product waste rather than resort to post-consumption disposal via a hose. It is advisable to ensure the floors remain dry, as this practice facilitates the identification of potential leaks.
- Prior to rinsing the piping system and tanks with water, it is imperative to ensure that they have been completely emptied.

## **2. Cheese Production Area**

- Please exercise caution when filling open cheese vats to avoid overfilling. It is recommended to cease filling once the milk level is at least 10 cm below the rim.
- It is important to handle the collection of whey with the utmost care and explore potential commercial applications for it, rather than simply discarding it as waste.
- Rather than disposing of curd by flushing it down the gutter with water, it should be collected and treated as solid waste.

## **3. Butter Production Area**

- Cream and butter adhere more easily than milk to surfaces upon contact, and their presence can exacerbate the contamination of wastewater unless they are eliminated prior to the commencement of cleaning procedures.
- Following the conclusion of a butter production run, it is necessary to manually remove any residue from all reachable surfaces.
- The cream and any remaining butter can be extracted using a combination of steam and hot water, and subsequently gathered in a designated container for individual processing.

## **4. Milk Powder Production Area**

- In order to prevent excessive cooking, it is recommended to operate the evaporators with a gentle approach.
- The condensate can be reused as cooling water subsequent to its passage through a cooling tower, or alternatively, it can be utilized as boiler feedwater.
- Spilled dry goods should be promptly cleaned up and appropriately disposed of as solid waste.

## **5. Milk Packaging Area**

- The filling devices may be equipped with drains that empty into one or multiple containers.
- The combination of sweet and sour liquids can be extracted from returned products and repurposed as animal feed.

## **VI. CONCLUSIONS**

The dairy industry is a significant sector in food processing, relying heavily on a substantial water supply and producing significant amounts of dairy effluent. The heterogeneity of waste composition varies across different industries, highlighting the requirement for supplementary data regarding the composition of wastewater streams. From a holistic perspective, the substance exhibits elevated levels of organic matter, biological oxygen demand (BOD), chemical oxygen demand (COD), and temperature. The improper management and direct utilization of this substance on the ground can give rise to significant ecological issues, posing potential ramifications for human communities, aquatic fauna (e.g., fish), and agricultural methods.

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