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Advances in Research of Characteristics, Environmental Impact and Treatment Methods of Dairy Wastewater

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Abstract Dairy wastewater, a kind of high concentration organic wastewater, is produced in large quantities and difficult to treat, and has a negative impact on the ecological environment. In this study, the source, composition, water quality characteristics of dairy wastewater and its impact on the ecological environment were analyzed, and the treatment methods of dairy wastewater at home and abroad in recent years were summarized, in order to provide a reference for the treatment of dairy wastewater.

Key words Dairy products, Wastewater, Treatment methods, Advances in research

0 Introduction

The statistic data of the Food and Agriculture Organization (FAO) of the United Nations (UN) in 2020 revealed that the global milk production was about 852 million tons and is growing steadily[1], and it is expected to reach 997 million t by 2029[2]. For China, according to *China Light Industry Yearbook*, the output of dairy products of enterprises above designated size was 27.803 8 million t in 2020, with a year-on-year increase of 2.84%[3]. With the increase of dairy production, the wastewater produced in the process of dairy production also increases.

1 Overview of dairy wastewater

1.1 Sources of dairy wastewater Water plays a key role in the production and processing of dairy products. Cleaning, washing, sterilization, pasteurization, heating, cooling and other processes[4] are inseparable from water, and 50% to 80% of the total water consumed by dairy enterprises is converted into wastewater[5]. The production processes of different dairy products are different, and the sources of wastewater are also different, but they are basically composed of waste milk, cleaning wastewater and process wastewater[6]. Waste milk comes from the part lost in the process of processing fresh milk into dairy products, which accounts for 1% – 3% of the total amount of fresh milk[7]. Cleaning wastewater is the wastewater produced when cleaning the equipment in direct contact with milk or dairy products[8], which mainly comes from the wastewater produced by cleaning milk delivery vehicles, tanks, pipelines and scouring production workshops, ground and other places. The process wastewater is the steam and condensate generated by the dryer and cooler during the processing of dairy products and the cooling water generated during pasteurization. Although this kind of wastewater may contain whey droplets and other volatile substances[9], it is generally clean dairy wastewater with few pollutants and can be reused for production and processing, room cleaning, lawn watering, and so on.

1.2 Characteristics of dairy wastewater quality According to the sources, dairy wastewater is equivalent to milk diluted several times, and its composition is basically the same. Generally, dairy wastewater presents the following characteristics. (i) High organic content. Although the organic compounds in the wastewater may vary depending on the composition of the target product and the production process used[8], it is undeniable that the dairy wastewater mainly contains carbohydrates, fats and sugars from milk, mainly lactose, milk protein and milk fat. In addition, dairy wastewater also contains cleaning liquids such as detergents and disinfectants produced by washing various equipment containers and the ground, and the main pollution components are sodium hypochlorite and caustic soda. Studies have shown that dairy wastewater usually has the characteristics of high chemical oxygen demand (COD) and five-day biochemical oxygen demand (BOD_5), and the concentration of COD can even reach 90 g/L[10], which belongs to high concentration organic wastewater. (ii) It has good biodegradability and is easily degraded by microorganisms. The concentration of COD and BOD_5 in dairy wastewater is high, and the ratio of BOD_5/COD is between 0.4 and 0.8, which has good biodegradability. (iii) The quality of wastewater varies greatly. Due to the wide variety of industries in the dairy industry, the water quality components of the wastewater produced by them are quite different[11]. For example, in the manufacturing process of ghee, the wastewater contains a higher concentration of lipids; there are nitrogenous compounds and other complex organic matters in the dairy wastewater[12], and the organic nitrogen substances can also produce ammoniation reaction under certain conditions, thereby increasing the concentration of ammonia nitrogen in the wastewater, and the concentration of TKN (Kjeldahl nitrogen) can reach 78 – 145 mg/L[13]. (iv) The pH of the wastewater changes greatly. Dairy wastewater is milky white, and its pH is generally in the range of 6.5 – 8.0. Due to the rapid fermentation of sugar-producing lactic acid, dairy wastewater can sometimes be acidic. Foreign studies have shown that the pH of dairy wastewater fluctuates between 4 and 10. (v) Wastewater volumes and flow

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rates vary widely. During the production process, it is found that the amount and flow rate of dairy wastewater vary greatly, which is related to the different production cycles in different milk processing units, and is affected by the season and the frequency of cleaning equipment. In general, the amount of water increases significantly when equipment is cleaned in the early morning and at night within the same day.

1.3 Impact on ecological environment If discharged directly without treatment, the high concentration of pollutants in dairy wastewater will aggravate the eutrophication and degradation of natural water bodies[14] and cause harm to aquatic ecosystems[15]. Studies have shown that one of the major issues in milk production is its impact on water and biodiversity, often triggering the proliferation of algae and bacteria, which can deplete substantial oxygen levels in aquatic environments, ultimately leading to the gradual disappearance of fish populations[16]. Dairy wastewater has high turbidity[12], which may lead to sewer corrosion[17]. In addition, If not promptly and effectively treated, the high concentrations of organic matter in dairy wastewater can rapidly decompose proteins, generating foul-smelling gases such as hydrogen sulfide and trimethylamine. These emissions can induce adverse symptoms like nausea and vomiting, posing significant risks to human health[18]. Dairy wastewater is also the basis of many emerging pollutants, especially hormone-containing compounds, which eventually enter the ecological environment with industrial emissions.

2 Treatment method of dairy wastewater

2.1 Physicochemical treatment The method is formed by combining a physical method and a chemical method, and is mainly used for treating colloids or suspended matters formed by sugar, whey, milk fat and protein contained in the dairy product wastewater. Physicochemical methods mainly include air flotation, coagulation and sedimentation, electrochemistry, membrane treatment and other methods.

2.1.1 Air flotation method. Air flotation technology is a water purification method in which a large number of highly dispersed micro-bubbles are introduced into the water to be treated, so that they can be used as carriers to adhere to the impurity flocs, forming a floating body whose overall density is less than that of water and floating to the water surface to complete the separation of solid and solid, solid and liquid, liquid and liquid in the water. Air flotation technology was first used in mining and metallurgical industry. Air floatation can effectively remove the lipid and suspended solids in dairy wastewater, and the dissolved organic matter can be further treated by aerobic process. Zhou Binbin *et al.*[19] adopted the combined process of "air floatation + hydrolysis acidification + biological contact oxidation", so that the removal rates of COD_{Cr} and BOD_5 in dairy wastewater reached 96.7% and 97.7%, respectively, and the treatment effect was stable and up to the standard. Ji Xiaofei[20] discussed the application of "air flotation + hydrolysis acidification technology + biological contact oxidation technology" in dairy wastewater treatment, and found that the process has the advantages of simple process, good treatment effect, low operating cost and less investment.

2.1.2 Coagulation and sedimentation. Foo and Hameed[21] added dried rice husk and rice husk ash as coagulant to dairy wastewater, and the results showed that the indicators of COD, BOD, turbidity and total suspended solids before and after rice husk treatment were greatly reduced, and good results were achieved. Banerjee and Dastidar[22] studied the treatment of dairy wastewater with jute processing waste, and the results showed that *Corchorus capsularis* processing waste could effectively reduce the concentration of key indicators such as COD and BOD in dairy wastewater, and had better adsorption effect and lower cost than granular activated carbon. Muniz[23] extracted natural coagulant *G. ulmifolia* from birch stem bark, and studied its removal effect on COD and turbidity in dairy wastewater. The results showed that *G. ulmifolia* had the characteristics of high efficiency, low cost, novelty and environmental protection. Tian Ying *et al.*[24] studied the treatment effect of boron sludge composite coagulant on dairy wastewater under different conditions such as pH, temperature and stirring time, analyzed and compared the cost of treating dairy wastewater by polymeric alumina and boron sludge composite coagulant, and concluded that boron sludge composite coagulant can be applied to the pretreatment of dairy wastewater. Cao Peihua *et al.*[25] studied and discussed the polymer flocculant PASS prepared with aluminum sulfate and sodium silicate as raw materials, which has electrostatic neutralization, adsorption bridging and net capture effects on colloid in the coagulation process, and the experiment proved that it has good effect on coagulation treatment of dairy industry wastewater.

2.1.3 Electrochemical method. Davarnejad *et al.*[26] carried out an experiment on the treatment of dairy wastewater by using the iron electrode electro-Fenton process, and evaluated the effects of reaction time, current density, pH, *etc.* on key indicators such as COD removal. Akansha *et al.*[27] used aluminum and iron electrodes to treat dairy wastewater by electrocoagulation, tested the influence of various parameters, and combined with phytoremediation technology, and the experimental results showed that the COD removal rate reached 97%. Zakeri *et al.*[28] studied the effects of polyaluminum chloride concentration and other parameters on pH, reaction time, voltage and electrode distance in the electro-Fenton process. Under the combined process of chemical coagulation and electro-Fenton, the removal rates of COD and BOD were 90.3% and 87.2%, respectively.

2.1.4 Membrane treatment. Membrane treatment technology is becoming more and more prominent in the practice of wastewater remediation. It can effectively remove pollutants, is environmentally friendly, easy to operate, and can also recover useful substances from wastewater. Membrane treatment is carried out on the basis of pretreatment such as flocculation to remove pore-clogging pollutants. Membrane treatment technologies such as microfiltration, ultrafiltration and nanofiltration are used to separate lactose, soluble salts, proteins and other substances in dairy wastewater.

At the same time, there are also problems of membrane pollution and high cost[29]. Zhou Chongwen *et al.* [30] prepared polyacrylonitrile/ferroferric oxide hybrid ultrafiltration membrane in the experiment, studied and discussed the influence of ferroferric oxide content on the permeation flux and retention rate of ultrafiltration membrane, and investigated the treatment effect and pollution resistance of ultrafiltration membrane with dairy wastewater. Sisay *et al.* [31] explored the performance of the composite photocatalytic membrane prepared by incorporating a variety of nanoparticles (TiO_2, carbon nanotubes, $BiVO_4$) into polyvinylidene fluoride membrane materials for actual dairy wastewater treatment, and they found that compared with the original membrane, the composite photocatalytic membrane showed better anti-fouling performance, lower filtration resistance, better flux and higher flux recovery rate.

2.2 Biological treatment In practical application, dairy wastewater is often treated by biological treatment methods because of its good biochemical properties.

2.2.1 Algae treatment. Gu Liwei *et al.* [32] used unicellular Chlorella to treat dairy wastewater, and discussed the growth capacity and pollutant treatment capacity of Chlorella in dairy wastewater with different contents, as well as the fuel extraction capacity of biomass cultivated by Chlorella in dairy wastewater. The experimental results show that about 80% of phosphorus and 70% of nitrogen in the dairy wastewater can be removed by *Chlorella vulgaris*, and the mass fraction of dairy wastewater before oxidation is 75%, which is more suitable for the growth of *Chlorella vulgaris*, and the biomass obtained by *Chlorella vulgaris* in the treatment of the wastewater has potential biofuel extraction capacity. Ma Meng[33] studied the growth characteristics and metabolite yield of 10 kinds of algae cultured by dairy wastewater, screened out 3 kinds of algae that can tolerate high concentration of COD and produce high biomass, and proposed the treatment strategy of dairy wastewater based on algae. He also calculated that a PBR in a dairy wastewater treatment station will produce 1.44×10^6 kg biomass/yr and fix 2.59×10^6 kg CO_2/yr. Based on the above research, he proposed that future research should focus on pilot-scale PBR in natural environment and large-scale treatment of dairy wastewater.

2.2.2 Actinomycetes treatment. Xie Liying *et al.* [34] studied the ability of Pseudomonas sphaeroides to treat dairy wastewater after adding Mg^{2+}, and the results showed that the optimal Mg^{2+} dose was 15 mg/L, and the COD removal rate reached 96%.

2.2.3 Direct treatment of acclimated activated sludge. Zhang Pengju *et al.* [35] added the acclimated activated sludge into SBR to conduct the direct biodegradation test of low-concentration dairy wastewater, and mainly investigated the removal effect of COD and NH_3-N. When the influent concentration of COD and NH_3-N were 1 654 and 115 mg/L, the effluent concentration of COD and NH_3-N were 66 and 2 mg/L, respectively. The results show that it is feasible to treat low concentration dairy wastewater directly by acclimated activated sludge.

2.2.4 Microbial fuel cell. Song Lei *et al.* [36] used dairy wastewater as the substrate in the anode chamber to construct a dual-chamber microbial fuel cell (MFC) reactor. Sludge mixed bacteria in the anaerobic tank were used as the biocatalyst, and different concentrations of $KMnO_4$ solution and dissolved oxygen (DO) were used in the cathode chamber as the electron acceptor to adjust the MFC impact factor to correspond to the anaerobic tank. The experimental data were calculated and compared with the wastewater treatment effect of anaerobic tank, and the electricity production performance of MFC was observed. The results showed that the electricity generation efficiency and stability of the two-chamber MFC increased with the increase of $KMnO_4$ concentration in the cathode chamber. When DO was used as the electron acceptor, the electricity generation performance of the MFC was lower, and it had the advantages of low cost and no pollution. After the treatment of dairy wastewater by different groups of MFCs, the removal rate of COD was better than that of the common anaerobic tank. Sahar *et al.* [37] studied using *Synechococcus* sp. as the cathode chamber and dairy wastewater as the anode chamber, through different experiments such as batch feeding, semi-continuous feeding, Synechococcus feeding in the anode chamber, Chlorella mixed system, treated wastewater feeding in the cathode chamber, and the use of additional nutrients in the anode chamber. The performance of a photo- and microbial fuel cell (PMFC) system was investigated. The results show that the PMFC with semi-continuous feeding mode is more effective than batch mode in power generation and pollutant removal. Obaid *et al.* [38] studied the construction and testing of a microbial fuel cell with *Saccharomyces cerevisiae* as the anode chamber. The experiment was carried out in 2 stages: in the first stage, the synthetic dairy wastewater from Saccharomyces cerevisiae in the anode chamber was used as the substrate at different pH (5, 6, 7, 8) and different operating temperatures (25, 30, 34 ℃) to evaluate the performance of MFC in terms of COD reduction and power generation; in the second stage, the MFC test was conducted using dairy wastewater with an initial COD concentration of 2 610 mg/L, inoculated with *S. cerevisiae* in an anaerobic anode chamber under optimal operating conditions. The results showed that the increase of operating temperature had a significant effect on COD reduction and operating time, and the optimum pH and temperature were 6 and 34 ℃, respectively. After the treatment of dairy wastewater, the removal rates of COD, TSS (total suspended solids) and TDS (total dissolved solids) of MFC were 92.0%, 79.3% and 62.5%, respectively. The ability of live microorganisms to digest organic matter in dairy wastewater and generate electrical energy was confirmed, and the maximum values of voltage and current were 850 mV and 28 μA, respectively. Therefore, microbial fuel cell technology provides an effective method for dairy wastewater treatment and energy recovery. Das *et al.* [39] used dairy wastewater as a substrate to understand the long-term performance of an air-cathode single-chamber MFC running for 95 d, and experimentally observed that the maximum removal rates of the MFC for COD and nitrate were 93% and

100%, respectively, and the power density was 0.48 W/m^3. MFC, an emerging technology in the dairy industry, can be used to treat dairy wastewater in the anode chamber, which will reduce the organic load of subsequent treatment units and thus reduce operating costs. More research is needed in the future, focusing on the progress of affordable and stable electrocatalysts[5].

2.3 Ecological treatment method Wang Shi[40] combined the sewage land treatment technology with soil freeze-thaw alternation to study its treatment effect on dairy wastewater, and mainly studied the removal effect of disturbed soil and undisturbed soil on total nitrogen in dairy wastewater and the environmental benefits of nitrogen. The results showed that the average concentration of total nitrogen in dairy wastewater was reduced from 122.85 to 13.48 mg/L, and the average removal rate was 89.03%. The removal of total nitrogen was related to temperature, and low temperature was not conducive to the removal of total nitrogen. Licata *et al*.[41] studied the treatment of dairy wastewater by horizontal subsurface flow wetland systems (HSSFs) and the effect of plants on the removal efficiency of BOD_5, COD, total nitrogen and total phosphorus. During the 3-year study, major chemical and microbiological characteristics and pollutants were identified, plant growth analysis and biomass accounting were conducted. It was found that the average removal rates of BOD_5 and COD were 77.8% and 61.6%, respectively, and the removal rates of BOD_5 and COD changed seasonally with the growth rate of plants.

3 Conclusions

In recent years, the research on the treatment technology of dairy wastewater in China has become increasingly in-depth. According to the literature at home and abroad, physical-chemical method, biological treatment method and ecological treatment method have their own advantages and disadvantages. In the future, on the basis of drawing on the experience of relevant advanced treatment technologies, we should adhere to the concept of source treatment and systematic treatment of dairy wastewater, strengthen the research on biological treatment and ecological treatment of dairy products, and coordinate the promotion of carbon reduction, pollution reduction, green expansion and growth, so as to promote the green, low-carbon and high-quality development of dairy industry.

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