

## Biological Treatment of Dairy Wastewater: A Mini Review

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**ABSTRACT.** The dairy industry is one of the primary water consumers. It produces a large quantity of wastewater with a high concentration of solids, nutrients, fat, and organic compounds characterized by biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Therefore, the treatment of dairy wastewater attracts increasingly more attention. The purpose of the paper is to provide an overview of biological treatment processes for dairy wastewater treatment, including one-stage and two-stage biological processes. The advantages, disadvantages, and limitations of aerobic and anaerobic technologies have been summarized and discussed in detail. Two-stage biological systems are also analyzed. In conclusion, the combined anaerobic and aerobic systems are determined as the most promising technologies for dairy effluent treatment in terms of the quality of the treated water.

*Keywords:* anaerobic treatment, aerobic process, two-stage biological system, dairy wastewater

### 1. Introduction

With the improvement of the socioeconomic level, the consumption of dairy products is also getting an increase. The Canadian dairy industries provide about \$18.9 billion to gross domestic product (GDP) and maintain approximately 215,000 jobs in 2019. In general, 60% of dairy production is sold as raw milk in Canada while the remaining milk is refined into other products. Productions of main products are cheese, yogurt, hard ice cream, skim milk powder, and butter. Canadian dairy products are known for their high quality and are recognized by other countries.

The dairy industry is also regarded as one of the primary waters consuming industries in the world. It produces a large amount of wastewater and discharged to aquatic ecosystems directly. The major sources of dairy wastewater are from cleaning and washing operation units in the dairy processing plants. The dairy wastewater is characterized by high BOD and COD, and generally contain fats, nutrients, lactose, as well as detergents and sanitizing agents. The characteristics of dairy wastewater vary significantly due to different operating procedures used in dairy plants. Currently, most of the dairy industries discharge untreated dairy wastewater directly to receiving waters. These contaminants in the wastewater negatively affect the quality of the receiving water and pose a threat to the living species including human beings, aquatic lives, and plants. Nutrients in the dairy wastewater cause eutrophication which may lead to offensive

odor problems in the receiving waters. It has also been reported that the formation of hydrogen sulfide in the dairy industry wastewater often creates an odor to nearby areas and affects people's health (Shete et al., 2013). The dairy effluent also has a foul odor and heavy black flocculated sludge mass due to high butyric acid and protein concentration. Therefore, the dairy wastewater should be treated before it is discharged to the receiving waters. Enforcement of strict dairy wastewater discharge permits would facilitate environmental sustainability. To meet the discharge permits, the dairy wastewater needs to be treated before its discharge. Therefore, it is urgent to find cost-effective dairy wastewater treatment systems. In recent years, various physical, chemical, and biological processes for dairy wastewater treatment have been developed. A chemical treatment that includes reagent oxidation and pH correction is mainly used to remove colloid and soluble pollutants produced in the milk processing. Phosphorus and heavy metal can be removed in the chemical treatment. In general, chemical reactions with  $\text{FeSO}_4$  and  $\text{H}_2\text{O}_2$  can remove up to 80% of the fat (Vlyssides et al., 2012). The physicochemical method, such as precipitation and coagulation-flocculation, is a promising approach for the wastewater treatment. More specifically, conventional thermal heating has been proved to successfully increase the biodegradability of dairy wastewater sludge (Beszédes et al., 2011). In comparison, biological technologies are more suitable for the treatment attributed to lower costs, simpler operation, and easier maintenance.

Many different types of biological treatment processes have been used to treat dairy wastewater, including sequencing batch reactor (SBR), moving bed biofilm reactor (MBBR), membrane bioreactor (MBR), rotating biological contactors (RBC), anaerobic sludge blanket bioreactors (UASB), and constructed wetlands (CW). In this article, biological processes for dairy

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wastewater have been reviewed and discussed. The advantages, disadvantages, and limitations in the aerobic, anaerobic, and two-stage treatment technologies for the treatment of dairy wastewater, and the areas in which further research is needed, have been identified.

## 2. Treatment Approaches

### 2.1. One Stage Biological System

#### 2.1.1. Anaerobic Process

Anaerobic systems, compared with aerobic systems, are more suitable and more cost-effective for the direct treatment of dairy wastewater which has suspended solids, high contents of organic matters, nitrogen, and phosphorous (Ahmad et al., 2019). Unlike the aerobic process, it does not require excessive energy and is an ideal approach for dairy wastewater treatment, because of the high concentration of COD and organic component and warm character of dairy effluents. In fact, various anaerobic systems have been successfully employed in dairy industry treatment, including up-flow anaerobic sludge blanket (UASB), anaerobic filter reactors, completely stirred tank reactor (CSTR), anaerobic digestion (AD) and membrane anaerobic reactor system (MARS) (Chan et al., 2009; Kushwaha et al., 2011; Slavov, 2017).

Up-flow anaerobic sludge blanket (UASB) reactor is one of the most commonly and successfully applied high-rate anaerobic approach for the treatment of mill processing effluents for almost 2 decades (Nadais et al., 2010; Slavov, 2017). It is made by two main parts: a cylindrical or rectangular column, and a gas liquid solid separator (Lettinga and Hulshoff, 1991, 2017). The influent enters the UASB bioreactor from the bottom and flows upwards towards the top of such bioreactor. During this process, the soluble organic matters in the wastewater are degraded by a blanket of granular sludge which suspends in the tank. The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants and small sludge granules begin to form whose surface area is covered in aggregations of bacteria. With these economical and simple operation, a high concentration of active suspended biomass can be formed and retained. In the meantime, biogas, including methane, is generated from bioreaction. However, the long solid retention time and start-up period will lead to the increased risk of insufficient organic-component removal and the high pathogen concentrations in the final effluent (Chong et al., 2012). Consequently, the effluent may not meet the requirement for discharge.

For the dairy sector, UASB bioreactors are largely suitable for the treatment of heavily polluted effluent with COD between 3000 and 40,000 mg/L (Buntner et al., 2013). More specifically, Ramasamy et al. (2004) applied a UASB bioreactor for dairy wastewater treatment under conditions of 3 and 12 hours of hydraulic retention time (HRT) and COD loading rates ranging from 2.4 to 3 kg/(m<sup>3</sup>·d). It achieved a COD reduction of 95.6 ~ 96.3% at 3 hours of hydraulic retention time (HRT) and 90 ~ 92% at 12 hours of HRT, respectively. In order to further enhance the efficiency of UASB, Nadais et al. (2005b) com-

bined flocculent sludge with UASB bioreactors and investigated the influence of HRT (6, 8, 12 and 16 h) on the performance. It was found by that at HRT over 12 hours, approximately 80% of protein and over 60% fat would be removed, while soluble COD and volatile fatty acid would be successfully degraded. Besides, Nadais et al. (2005a) also accessed the effects of cycle duration on the intermittent operation of mesophilic UASB reactors inoculated with flocculent sludge. It was found that with 96 hours cycle (48 hours feed and 48 hours feed-less), the optimum for the treatment of dairy effluents in intermittent UASB reactors, highest conversion to methane of the removed COD was obtained resulting in a more stable operation. However, the enormous number of organic matters easily accumulate in the sludge blanket because of entrainment and adsorption, requiring higher hydrolysis or degradation times (Passeggi et al., 2012). Ozturk et al. (1993) reported a laboratory-scale hybrid up-flow anaerobic sludge blanket reactor (HUASBR) and its application on dairy wastewater from a large integrated industry with a maximum daily production capacity of 500 tons milk. According to the result, the modified reactor was able to remove 87% of COD under HRT 0.21 ~ 0.96 day and organic loading rate (OLR) of 8.5 kg COD/(m<sup>3</sup>·d). Passeggi et al. (2012) investigated a modified UASB reactor with a scum extraction device and a lamella settler, which presented a significantly greater performance than the traditional approach, removing 90% of COD in comparison to 22% of COD while traditionally HRT is used.

Anaerobic filter (AF) is a representative attached-growth process that has been favorably considered for the treatment of dairy industrial wastewater (Jo et al., 2016). It consists of an anaerobic digestion tank which contains a filter medium. The large specific surface of this filter media provides a precondition for the immobilization and accumulation of the activated microbes, reduces the effects of shear stress and enables tolerance to extremely high organic loading rates (Rajeshwari et al., 2000). Up-flow anaerobic filter (UFAF) with 50 mm polypropylene plastic media was found to remove more than 85% of COD and 90% of BOD under the high organic loading rate (OLR) of 6 kg COD/(m<sup>3</sup>·d) and an HRT of 20 h, with approximately 770 liters CH<sub>4</sub> produced per day (Ince, 1998). In the meantime, appropriate materials have a significant influence on the attachment of biomass and functioning of anaerobic filters, and can support the formation of biofilms in anaerobic filters (Loupasaki and Diamadopoulos, 2013). The performance of anaerobic filters is strongly affected by the properties of packing materials, including size, shape, porosity, and specific surface area. Therefore, a great number of researches were focused on the application and modification of packing materials.

For example, Anderson et al. (1994) studied a couple of porous and non-porous media in two mesophilic anaerobic up-flow filters treating a wastewater from a milk bottling factory. This reactor with porous packing performed better (OLR, expressed as COD, of 21 kg/(m<sup>3</sup>·d)) than the same reactor with non-porous packing (OLR, expressed as COD, of 4 kg/(m<sup>3</sup>·d)). It has also been reported that after lactic acidification and lime neutralization, the up-flow anaerobic filter could achieve 80 ~ 90% average total COD removal, under the condition of 2 ~ 5

d HRT (Gannoun et al., 2008). In the meantime, Ince et al. (2000) examined the strength and performance of a porous media (sintered glass media) in an up-flow anaerobic filter (UFAF). It was reported that *Methanococcus* as well as short rods, medium rods, long rods, filaments and *Methanosarcina* were the dominant species in the attached biomass. This reactor was operated and achieved an average COD removal of about 80% under an OLR of 21 kg COD/(m<sup>3</sup>·d) and an HRT of 0.5 d.

However, UFAF is more suitable and recommended for the treatment of soluble wastes which can be diluted by recycling effluent, as the attached biomass tends to get accumulated at the bottom of UFAF, causing heavy clogging. In order to troubleshoot such problem, a down-flow anaerobic filter (DFAF), where sloughed biomass is going to be released from filter along with the effluent, is introduced (Jawed and Tare, 2000). Yeadam et al. (2016) investigated a downflow anaerobic filter packed with granulated blast-furnace slag (BFS) for treating cheese whey and COD removal remained at around 80%, with the reactor pH being maintained neutral without buffering, in the organic loading rate (OLR) range of 0.8 ~ 2.4 g COD/(m<sup>3</sup>·d). Besides, Jawed and Tare, (2000) examined and analyzed the performance of DFAF operated under similar environmental conditions for over 20 months. As this research presented, the main components of solids retained in DFAF packing media were black granules with a diameter of 3 ~ 5 mm, while most components in UFAF were brown-black granules (2 ~ 3 mm). The estimated concentration of retained solidly in DFAF (76.39 g TS/L) was much higher than that in UFAF (69.91 g TS/L), indicating the more compact properties of retained solids in DFAF.

#### 2.1.2. Dairy Wastewater Aerobic Treatment Process

Dairy wastewater contains mainly solids, BOD, ammonia, nitrite, nitrate, milk protein, fat, amino acid, urea, uric acids, trivial nitrogen ammonia salt, and phosphorus. Of which, the BOD can be readily removed, and ammonia can be oxidized to nitrite and nitrate during the aerobic process, the removal of the rest contaminants needs both aerobic and/or anaerobic process.

Currently, SBR, MBBR, and MBR are widely used for dairy wastewater treatment (Banu et al., 2007; Prazeres et al., 2012). These processes are based on an activated sludge aerobic process, along with some anaerobic zones in the bioreactor for nutrient removal. It was reported that an aerobic process is much more cost-effective than an anaerobic process for removing the fats in the dairy wastewater. It was also found that an appropriate pre-treatment is essential to improve the biological nutrients removal (Rivas et al., 2011).

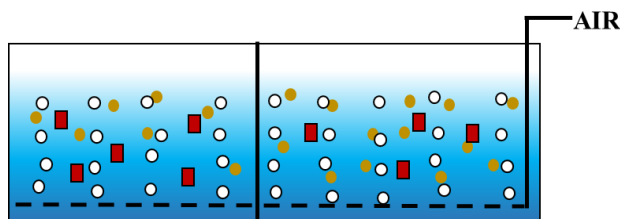
The SBR accomplished treatment over a series of time steps in a single bioreactor (Metcalf and Eddy, 2003). The aerobic and anaerobic stages are timed instead of the wastewater being transferred to a separate reactor. The timing of the aerobic and anaerobic phases can be achieved using an aerator. The SBR process consists of five treatment cycles implemented in a timed sequence of fill, react, settle, decant, and idle. In the fill stage, the dairy wastewater fills the bioreactor, where it is combined with the mixed liquor containing microorganisms for

the treatment. The microorganisms then remove the contaminants in the react cycle through aerobic and anaerobic reactions such as nitrification and denitrification. Once the reactions are done, the mixing device and aerators are stopped to provide a quiescent condition for suspended solids to settle. Once the solids have settled, the supernatant effluent is decanted out of the bioreactor. At the final stage of the SBR process, the bioreactor is left to idle. The idle phase is needed in the multi-tanks SBR treatment process to provide plentiful time to operate the fill before switching over the next unit. As mentioned above, the SBR accomplished biodegradation and sedimentation in a single bioreactor, the SBR is suited for use in small agricultural communities like dairy industries. The flexible operation, small capital cost, small footprint, and easy control are the advantages of the SBR compared with other biological aerobic treatment (Singh and Srivastava, 2011). However, the sophistication of operation is needed when the dairy wastewater flowrate is high (Kassab et al., 2010).

The SBR has become an auspicious dairy wastewater treatment technology (Slavov, 2017). As reported in previous studies, the nutrients substrate has been reduced by 95% in COD, by 60% in TS, by 40% in total nitrogen (TN), by 74% in total Kjeldahl nitrogen (TKN), and by 58% TS in treatment of dairy effluent with SBR (Hung et al., 2005). The efficiency of nutrients removal in SBR is determined by the operation parameter, like temperature, aeration (dissolved oxygen concentration), HRT (hydraulic retention time), the time of phase, the volume of the reactor, and so on. A study has reported that more than 90% of COD in the industrial dairy wastewater was treated by aerobic SBR with COD from 2,400 to 3,800 mg/L, dissolved oxygen concentration from 2 to 3 mg/L, and the MLVSS about 3,000 mg/L (Bandpi and Bazari, 2004). The single-stage and the two-stage SBR treatment have been investigated by Li and Zhang (2002). The hydraulic retention time (HRT) is 4 days in single-stage treatment. The efficiencies of TKN, TN, COD, and total solids removal were 74, 38, 80, and 66%, respectively. Bae et al. (2003) developed an SBR system coupled with a membrane filtration for biological nitrogen removal. In this study, the removal efficiencies of phosphorus and nitrogen were 80 and 95%, respectively while the removal of BOD ranges from 93 to 98%. The organic loading in the SBR system coupled with a membrane is higher than SBR treatment (Neczaj et al., 2008). The HRT has a positive relationship with the removal efficiency, while the organic loading has a negative association with the removal efficiency in SBR systems. According to the statistics, the quality of dairy wastewater effluent was best under HRT of 10 days and 0.8 kg BOD/m<sup>3</sup> organic loading. An anaerobic sequencing batch reactor (ASBR) is similar to the aerobic SBR with a great contaminant removal efficiency. The ASBR does not have aeration in the cycle time. The dairy wastewater (Dugba et al., 1999) and brewery wastewater (Bergamo et al., 2009) have been treated by ASBR. Another kind of SBR is intermittently aerated sequencing batch reactor (IASBR), which was investigated to enhance the remediation limitation of nitrogen and phosphorous through the aerobic technology in the milk wastewater (Gil-Pulido et al., 2018). The main advantage of IASBR is to decrease the demands of infrastructural and

energy during the biological removal of nitrogen, COD, BOD, and phosphorus.

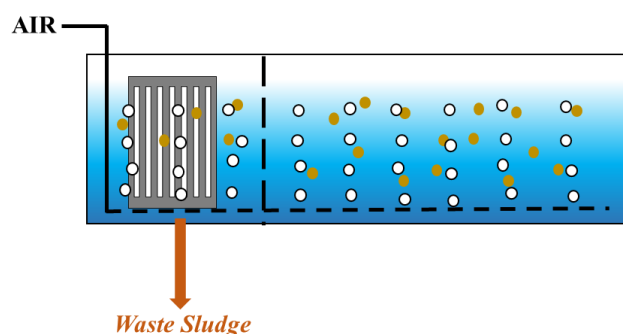
MBBR is a desirable choice at treating dairy wastewater. The MBBR process is a highly effective biological treatment process based on a combination of a conventional activated sludge process and biofilm media called biocarriers (Figure 1). A high capacity microorganisms lodge on the surface and inside biocarriers. Both aerobic and anaerobic zones can be found in the biocarriers when the bulk dissolved oxygen concentration is low. BOD removal and nitrification occur in the aerobic zones, and denitrification occurs in the anaerobic zone. Therefore, the MBBR can remove solids, BOD, nitrogen, and phosphorus from dairy wastewater. The advantages of using the MBBR are that it needs smaller reactor volume and simpler operation due to no need for manual sludge wasting, and no need for controlling solid retention time and sludge recycle. Compared to conventional activated sludge plants, the use of the MBBR also eliminates the concerns of sludge bulking in the secondary clarifiers and the sludge bulking effects on operation and effluent quality. Currently, the MBBR becomes a promising technology to treat dairy wastewater based on the larger surface to attach biomass and higher wastewater loads (Rusten et al., 1992). MBBR has good performance in terms of dairy wastewater treatment. The singlestage MBBR system could remove 80 ~ 97% of COD in dairy wastewater with a pre-treatment, but nitrogen removal ranges from 13 to 96% can be achieved, which makes it difficult to meet the surface discharge permit. An MBBR with biocarriers can remove 85 and 60 % of COD in the condition of 12 and 21.6 kg/(m<sup>3</sup>·d) at OLR, respectively. The MBBR could be used for the dairy farm wastewater treatment (Rusten et al., 1992).



**Figure 1.** Diagram of a typical MBBR bioreactor.

A membrane bioreactor (MBR) combines microfiltration with activated sludge process (Figure 2). The MBR has a stable ability to remove the high concentration of organic load and pathogens so that it is considered as a possible technology for dairy wastewater treatment (Li et al., 2009; Wu et al., 2013), when it is used in conjunction with some anaerobic treatment process for nitrogen removal. Separating bioflocs from the permeate during biological wastewater treatment is the main purpose of the membrane so that a secondary clarifier and a return activated sludge stream are not necessary. The MBR allows a high level of suspension biomass in the bioreactor and the volume of the reactor could be decreased during the treatment of dairy wastewater (Wu et al., 2013). Although MBR has a great potential to treat the dairy wastewater, the academic journal describing this application is not too many. The studies refer to

treat the dairy farm wastewater (Castillo et al., 2007; Hirooka et al., 2009), whey (Farizoglu et al., 2004), and domestic sewage (Bick et al., 2009), or to the combination of coagulation and MBR for dairy wastewater treatment (Chen and Liu, 2012). Treating the effluent with COD 13 kg/m<sup>3</sup> and BOD 7 kg/m<sup>3</sup> from ice-cream factory through membrane bioreactor would gain a high standard performance at 25 °C. As a result, more than 95% of COD and BOD could be removed, while total nitrogen and total phosphorus are reduced over 96% and 80%, respectively (Scott and Smith, 1997). There are no references to utilize the aerobic MBR to deal with the effluents from large dairy industries and the application of large-scale MBR is restricted (Frederickson, 2005). There are several factors that limit the wide applications of MBR: (1) the high capital and operational costs and (2) membrane fouling. Overall, membrane fouling is the major factor that limits the implementation of the MBR.



**Figure 2.** Diagram of a typical MBR bioreactor.

## 2.2. Two-stage Biological System

Two-stage process systems have been widely investigated and applied for the treatment of wastewater which contains large concentrations of organic components, including foods and agricultural industry effluent (Guerrero et al., 1999; Demirel and Yenigün, 2002).

In most cases, the anaerobic process was designed as a pre-treatment, because of its relatively lower construction and operation cost, simplicity of operation, less sludge produced, and less biogas generation (Lettinga, 1995; Kassab et al., 2010). When polyurethane foam and polyvinyl chloride rings were filled in a two-stage hybrid up-flow anaerobic sludge blanket (UASB) reactor, the UASB can remove as high as 98% of COD (Kotoupas et al., 2007). However, the anaerobic process can only be considered as a preliminary process in the dairy effluent treatment due to a weak removal of organic nutrient and carbon contaminants. If it is incorporated into an adequate post-treatment, especially for the aerobic reactor, the treated dairy wastewater could meet a local standard for discharge or agricultural reuse (Akunna et al., 1994; Tilche et al., 1994; Cheng et al., 2009; Karadag et al., 2015). For example, Garrido et al. (2001) and Omil et al. (2003) combined a full-scale plant comprising a 12 m<sup>3</sup> anaerobic filter (AF) reactor and a 28 m<sup>3</sup> SBR. With 5 ~ 6 kg COD/(m<sup>3</sup>·d) organic loading rates maintained in the AF, such a system was able to remove more than 90% of COD and obtained a final effluent with a COD less than 20 mg/L and total

**Table 1.** Comparison of Biological Processes for Dairy Wastewater Treatment

Reactor type	Waste type	HRT	OLR (kg COD/m <sup>3</sup> .d)	TSS		COD		BOD		TN		TP		Reference
				Influent (g/L)	Removal (%)	Influent (g/L)	Removal (%)	Influent (g/L)	Removal (%)	Influent (g/L)	Removal (%)	Influent (g/L)	Removal (%)	
UASB	milk	3 ~ 12 h	13.5	-	-	1440	96	-	-	-	-	-	-	Ramasamy et al., 2004
UASB	-	12 h	22.0	-	-	-	96 ~ 98	-	-	-	-	-	-	Nadais et al., 2005a
UASB	-	6 ~ 16 h	2.5	27.4	-	1900	70 ~ 93	-	-	-	-	-	-	Nadais et al., 2005b
UASB	milk	3.6 h	1.5	-	-	6800	90	-	-	-	-	-	-	Passeggi et al., 2012
UASB	ICE-cream	-	-	1100	-	4940	96	-	-	-	-	-	-	Hawkes et al., 1995
DFAFs	Cheese whey	5 h	0.8 ~ 4.0	18.4	-	4000 ~ 20000	80	-	-	271.7	-	213.5	-	Jo et al., 2016
UFAF	-	20 h	6.0	-	-	2000 ~ 6000	75 ~ 85	1200 ~ 4000	-	-	-	-	-	Ince, 1998
UFAF	-	12 h	4 ~ 21	-	-	1500 ~ 5500	62 ~ 90	1000 ~ 3000	-	50 ~ 60	-	4-6	-	Anderson et al., 1994
UFAF	Cheese whey	1 ~ 4 d	1 ~ 4	0.8	60	25000	80 ~ 90	20000	-	-	-	-	-	Gannoun et al., 2008
UFAF	-	20	-	-	-	5000	99	3786	-	56	92	43	-	Ince et al., 1998
CSTR	cheese whey	-	-	-	-	68600	-	7710	-	1120	-	500	-	Traversi et al., 2013
CSTR	-	-	-	5100	-	4000	99	2160	-	200	-	60	-	Carta-Escobar et al., 2004
SBR	-	36	-	413	100	-	-	2605	98	136	96	56.8	80	Bae et al., 2003
SBR	-	-	-	-	-	1674	95	-	-	-	-	-	-	Castillo et al., 2007
IASBR	-	-	-	-	-	3513	98	-	-	122.2	38	51.9	-	Gil-Pulido et al., 2018
AFBR	ICE-cream	8	-	3900	-	5200	99	2450	-	60	93	14	76	Borja et al., 1995
MBR	-	-	-	-	-	2143	97	-	-	-	-	-	-	Chen and Liu, 2012
MBR	-	-	-	1430	-	3620	99	2115	98	-	-	187	74	Mansoorian et al., 2014
JLMBR	Raw cheddar whey	30	-	12000	-	16000	98	-	-	-	-	-	-	Farizoglu et al., 2004

Continues

Reactor type	Waste type	HRT	OLR (kg COD/m <sup>3</sup> ·d)	TSS		COD		BOD		TN		TP		Reference
				Influent (g/L)	Removal (%)	Influent (g/L)	Removal (%)	Influent (g/L)	Removal (%)	Influent (g/L)	Removal (%)	Influent (g/L)	Removal (%)	
AMBBR	milk permeate	13	-	2670	-	55200	99	-	-	-	-	350	80	Wang et al., 2009
An SBBR	milk processing	-	-	-	-	4783	-	2860	99	62	92	50	-	Bezerra et al., 2007
ABR	-	-	-	4350	-	4590	-	-	-	89	93	9.9	-	Pretti et al., 2011
Two-stage UASB	cow dung slurry	56	-	3548	84	2000	97	-	-	-	-	-	-	Banu et al., 2007
UFAF + BAF	-	-	-	-	-	1203	99	-	-	-	-	-	-	AKunna et al., 1994
UASB + MBR	milk	-	-	-	-	1000 ~ 2000	99	-	-	-	-	-	-	Buntner et al., 2013
AF + SBR	milk	-	5-6	-	-	8671 ~ 12487	90 ~ 99	-	-	-	-	-	-	Omil et al., 2003
AF + BAF	-	-	0.66 ~ 0.73	194 ~ 548	-	1810 ~ 2431	80 ~ 87	-	-	131 ~ 160	51 ~ 81	-	-	Lim and Fox, 2011

nitrogen below 10 mg N/L. Lim et al. (2011) conducted the kinetic analysis and experimental validation of an integrated system of anaerobic filter (AF) and biological aerated filter (BAF). According to their data, the average COD removal efficiency was 79.8 to 86.8% in the AF and the average total nitrogen removal efficiency was 50.5 ~ 80.8% in the AF/BAF system. Buntner et al. (2013) achieved the combined UASB and MBR system for the treatment of dairy wastewater at ambient temperatures. Such a system exhibited high tolerance to organic loading rate changes (up to 4.85 kg COD/(m<sup>3</sup>·d)) and temperature fluctuations from 17 to 25 °C and removed average more than 95% of soluble COD.

Nevertheless, the substrates required for aerobic treatment are not appropriate for anaerobic reactor (Held et al., 2002). Lignocellulosic materials, which are difficult to be degraded in the anaerobic process, are particularly suitable for aerobic reactors improving the structure and C/N ratio (Vidal et al., 2001; Demirel and Yenigün, 2002). The aerobic composting process demands over 40% of solid materials which offer enormous pore volume, while such insoluble materials set a limit to the degradation rate of anaerobic treatment (Eastman and Ferguson, 1981; Held et al., 2002). In order to overcome this disadvantage, anaerobic/anaerobic systems are introduced. The combination of a completely mixed anaerobic digester as the preacidification reactor and an up-flow anaerobic filter (UAF) as the methanogenic reactor achieved 90% of COD and 95% of BOD removal efficiencies at an organic loading rate (OLR) of 5 kg COD/(m<sup>3</sup>·d) and an HRT of 2 days (Ince, 1998).

Meanwhile, more studies focused on different aspects of continuously stirred tank reactors (CSTRs) recently. Indeed, this technology is a good option for scientific research as a part of mixed systems, but it is difficult to realize the application of such a bioreactor in the industry as a result of the HRT restriction (Usack et al., 2017). For instance, CSTR and anaerobic baffled reactor (ABR) in series were able to treat low strength dairy wastewater and removed average of 82% COD with a biogas yield of 0.26 m<sup>3</sup>/kg, when fed at constant HRT of 1.6 days in the ABR with OLR between 1.25 and 4.50 kg COD/(m<sup>3</sup>·d) (Jürgensen et al., 2018). Two-stage CSTR-UFAF bi-reactors is a suitable system for anaerobic fermentation to efficiently degrade the liquid fraction of organic municipal waste, with an overall 80% of COD degradation efficiency at high OLR (13.1 kg COD/(m<sup>3</sup>·d)) (Held et al., 2002). Diamantis et al. (2014) reported a two-stage continuous stirred-tank reactor (CSTR) and UASB bio-system for anaerobic digestion of diluted cheese whey. The enhanced acidification system was capable to ensure up to 90% of COD removal in the UASB reactor and optimum methane yield values and was stable at organic loading rates up to 20 kg/(m<sup>3</sup>·d). Approximately 65 ~ 70% of nitrogen, 99% of BOD, and 92% of COD have been removed with the combination of pre-treating up-flow anaerobic sludge blanket (UASB)-septic tank and MBBR (Luostarinen et al., 2006). The COD, BOD, and total nitrogen removal efficiency in pure moving bed biofilm reactor-membrane bioreactors are 88.32, 90.34, and 60.21%, respectively (Díaz et al., 2017). The complicated moving bed biofilm reactor-membrane bioreactor has an excellent performance in nutrient removal. In addition, the integration of

the aerobic SBR and anaerobic RBC could meet 98% of BOD reduction along with methane gas generation (Goli et al., 2019). There are many advantages in the two-stage aerobic-anaerobic system, such as high removal efficiency, wide operation flexibility, low capital cost.

### 3. Comparison of Biological Treatment Performance on Dairy Industry Effluent

Table 1 presented the treatment performances of various biological treatment systems. According to the data, MBR can remove a large amount of BOD from high strength of dairy industry effluent with over 16,000 mg/L of COD and OLR of 12,000 kg COD/(m<sup>3</sup>·d). However, the nitrogen removal efficiency is extremely low due to the lack of anoxic zone for denitrification. The membrane fouling, low tolerance of flowrate fluctuation, high capital and operational costs have limited its application. The MBBR process can significantly decrease BOD in dairy effluent and enjoys various advantages, including small footprint, simple operation with no returned sludge as well as short HRT. Despite the high COD and BOD removal efficiencies, MBR and MBBR are not generally suitable for dairy wastewater treatment, due to the undesirable performance on the removal of TN and TP. Only in the case that bulk dissolved oxygen (DO) is relatively low, the anaerobic zone can be generated inside of flocs for denitrification and as a result, MBBR is able to remove nitrogen in effluent and to be used for dairy wastewater treatment. Consequently, SBR is regarded as the most promising technology for dairy wastewater treatment. This is because it can provide both aerobic and anaerobic zones by turning on/off the aerator. Therefore, it can remove BOD, nitrogen and phosphorus.

Compared with the aerobic process mentioned above, UASB and AF reactors are capable of dealing with the dairy wastewater with higher BOD, COD and organic loading rate. In addition, they require less energy produce less amount of sludge and generate large amount of methane that can be used as an energy source. Based on the data shown in Table 1, UFAF is the most promising treatment and performed more satisfactorily, especially at high loading rates. This reactor is more appropriate for dairy industries effluent with low concentration of suspended solid and can provide enough retention time for biosolid. Nevertheless, it showed undesirable responses to shock loading and as a result, it is necessary to offer satisfying suspended retention time and HRT. Moreover, alkalinity addition is required for the pH maintenance, due to the pH fluctuation during the digestion of lactose.

However, the treatment performance of UASB and AF bioreactors is lower than that of SBR, MBBR, and MBR reactors, while longer start-up time is demanded for anaerobic treatment to develop necessary biomass concentration. Meanwhile, it is impossible for these techniques to remove nitrogen and phosphorus biologically due to the lack of anoxic zone for denitrification. As a result, conventional one-stage anaerobic/aerobic treatment is now being replaced by two-stage biological treatment. In this combined process, the anaerobic process can be regarded as a preliminary step that must be polished for the reduction of most C-containing contaminants, whereas nutrient removal

is achieved by aerobic steps in order to meet discharge requirements.

#### 4. Conclusion

The dairy industry is one of the primary water consumers in the world and produces unstable and considerable wastewater with relatively high temperatures, variable pH values, high COD, BOD and nutrient concentrations. This study reviewed different biological processes currently developed for dairy wastewater treatment and discussed the advantages and disadvantages of each system in details. In general, MBR is not proper for treating dairy effluent, while MBBR may work only if the dissolved oxygen is low. SBR and UFAF are considered as the most suitable aerobic process, because of their excellent performance in terms of nitrogen, phosphorous, COD and BOD removal. Nevertheless, SBR showed poor performance when the dairy effluent flowrate is high, whereas anaerobic treatment is unable to deal with ammonia which is extremely toxic with high concentration and cannot produce clear streams. Hence, the combination of fermentative and aerobic processes can be a more proper solution for dairy wastewater treatment and gradually replace traditional one-phase biological process. Consequently, more researches should be focused on the removal of these two-phase biological treatment, including aerobic/anaerobic and anaerobic/anaerobic system, for the development of biological processes.

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