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Critical review on biological treatment strategies of dairy wastewater

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ABSTRACT

Dairy products are one of the richest sources of vital nutrients in the diet of human beings and it occupies an important place in satisfying their nutrient requirements. The dairy products possess a very short lifespan and during their decomposition create a huge nuisance to the environment. The dairy effluents discharged from the industries are mainly composed of complicated substances such as organic compounds, inorganic compounds, carbon, nitrogen, phosphorus, chlorides, sulphides, fats, oils, grease, etc. These organic loading present in the dairy effluent have a negative impact on the environment during its discharge to nearby water sources. The physical and chemical treatment of the dairy effluents is not as effective as the biological treatment. The biological treatment method is found to be the superior method for treating the dairy effluent. The biological wastewater treatment can be performed in two various conditions such as aerobic and anaerobic. The treatment methods such as aerobic lagoons, activated sludge, sequential batch reactor, trickling filter, completely stirred tank reactors, fluidized bed reactors, and anaerobic filters are some of the biological methods used in dairy effluent treatment. This review article has investigated in detail regarding the environmental impact of dairy effluents and their effective treatment using biological treatment technologies

Keywords: Dairy industry; Biological treatment; Aerobic; Anaerobic; Wastewater

1. Introduction

Water is a prodigious asset of nature and it is a fundamental component required for the basic functioning of all living organisms in the universe. It has got tremendous impact on the betterment of human life, nourishment production and in monetary advancements [1]. Most part of the surface of the earth is concealed by aqua; on the other hand around 98% of water sources present in the planet earth is incompatible for drinking purposes due to the elevated levels of dissolved salts in it. The rest of streams are partially inaccessible as it is clinched in the polar ice tops, icy masses, permeable rocks and underground excavations. Therefore, only a small proportion of clean water present in lakes and waterways are open to human needs [2]. The discharge of noxious industrial effluents and strong domestic waste into the aquatic ecosystem changed the quality of the water and causes a deficit of drinking water [3]. The augmenting surge in the urbanization and industrial sector altered the quality of freshwater and played a vital role in water deficit by extensively expanding the rate of contamination in the water sources. The shrinkage of water sources had a serious negative impact on the growth of the industries and it complicates the regular life of humans [4]. According to the reports of FAO 2009, it is stated that the consolidation of elevated population growth, lesser agricultural land, increasing pollution, soil disintegration, varying

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weather pattern, industrial pollution, etc., are some of the reasons for the major protein deficiency disorders in many countries [5]. Industries are said to be the major contributors to the growing economy of a nation. On the other hand, the outbreak of various kinds of industries into the environment caused water deficit which is known to be a dreadful issue faced by people living all over the world. The wastewater with less contamination is subjected to wastewater treatment and used for various purposes [6]. Wastewater treatment is an another important source to produce water by treating it economically and eliminating all the hazardous components from the effluent [7].

Food industry is one among the several kinds of commodious industries present in our modern environment. Especially, these industries utilize a huge amount of fresh water for their manufacturing unit and they are one of the leading industries which eliminate profluent vigorously. The dairy industry is one such industry categorized under the food industries. India is one of the dominant milk-producing country and it positions first in milk production among several other countries. Dairy industry is one of the noteworthy industry which discharges waste thrice the volume of milk produced, also it gushes out a vast amount of processed water in the vicinity of 3.739 and 11.217 mil lion m^3 of waste for every year [8]. This sector also increases the economic status of India [9]. Dairy industry possesses one of the major positions in Italy which contributes to about 6% of the total world's dairy commodity production. The dairy industry involves various process like cleaning, sanitizing, manufacturing, blending, heating and cooling from where a bulk amount of organic load is produced as effluent [10]. The wastewater eliminated from these kinds of industries comprises of the easily degradable lactose, along with some complex substances such as proteins, fats and oils. Other major substances such as nitrogen and phosphorus are present in the effluents as orthophosphate and other complex forms [11]. Effluent treatment is one of the essential unit in every manufacturing sectors and it is involved in eliminating the harmful components present in the effluent. This method is composed of several mechanical and biological operations which eliminate the organic, inorganic, suspended and dissolved compounds present in the released effluents. The treatment techniques also help in eliminating the pathogenic micro-organisms present in the industrial discharge and reduce its toxicity so that it does not create big consequences when discharged into water sources [12].

1.1. Dairy industry

From the very beginning, milk was considered as one of the greatest source of vital nutrients out of all other food products [13]. It is one of the nutritious liquid synthesized and secreted by the mammary glands of female mammals. As a result of the quick industrialization occurring everywhere throughout the nation, the number of dairies and united enterprises are pointedly rising [14]. Majorly, the milk is occupied by 87.5% of water and further, it is composed of 3.9% of fat, 4.8% of lactose, 3.4% of protein, 0.8% of minerals and 13% of solid compounds [15]. Dairy industry plays an important role in producing a large amount of sustenance handling wastewater in numerous nations. As it consumes a large amount of water for the manufacturing of the dairy products it remains as the biggest antecedent of food industrial wastewater [7]. Europe is one of the major continent which produce an immense amount of dairy effluents and a typical dairy industry in Europe produces around 500 m^3 of dairy effluents as a major waste containing large amounts of fats, proteins and carbohydrates [16]. A tremendous amount of fresh water is utilized in the unit operations including sterilization, heating, cooling, pasteurizing, cleaning and all other process involved in the preparation of dairy products. The impact of dairy wastewater on the environment results in formulations of stringent regulations on the release of industrial effluents [17]. Several advancements made in the animal husbandry lead to the progress in the dairy industry by increasing the milk production in the cattle through various scientific techniques. This development in the dairy industry helped several countries to meet their population's nourishment requirements [6]. Elimination of the organic loading composed in the dairy wastewater is mandatory to lower the harmful environmental consequence [18].

1.1.1. Characteristics of dairy wastewater

The composition of the organic compounds present in the effluents differs according to the products manufactured. Usually, in the cheese manufacturing process, a high amount of carbohydrates and protein are available in the effluents, while, in the manufacturing of ghee higher level of lipid is present in the effluent released [19]. The increase of cheese production in the industries gradually raises the dairy wastewater. Dairy industry consumes higher quantity of carbohydrates and proteins for the manufacturing and washing practices, further, dairy wastewater produced from these sectors is composed of higher fixation of nitrogen and other complex organic matter [20]. Basically, the dairy wastewater does not comprise of any highly toxic chemical substances as other industrial effluents. On the other hand, it is basically made up of a mixture of organic compounds such as lactose, whey proteins, nutrients and fats which causes bad odors and makes distress to the encompassing populace during its degradation stage [4]. The flow rate and ingredients of the effluents are not constant and they tend to fluctuate based on the manufacturing and production process [21]. The dairy wastewater is one of the wastewater with high organic content like other food industry effluent. In specific it is characterized by its elevated levels of chemical oxygen demand (COD) and biological oxygen demand (BOD) which becomes a major problem to the water source into which this wastewater is discharged [22]. The characteristics of the dairy effluents depend on the following features such as industrial scale, processing types, type of method, the efficiency of the method, process parameters, type of operation, selection of equipment for cleaning, type of waste discharged and cost required for treatment of wastewater [23]. Dairy industry contributes a major part in the production of a large volumes of industrial wastewater containing high organic load which cannot be eliminated easily [24]. Most of the governmental and ecological protection organizations have created many inflexible rules and regulations to decrease the harmful effects of the effluents discharged from the industries. The dairy wastewater is seen with high turbidity along with a large amount of solids, further, they contain a less amount of dissolved oxygen in it. The efficient treatment of dairy wastewater is an indispensable method to secure the freshwater bodies which receive the dairy wastewater from getting damaged by the noxious emission of nitrous oxide (NO) and ammonia (NH_3). Further wastewater treatment also saves the water bodies from the eutrophication which damages the quality of freshwater [20]. Color is a subjective trademark that can be utilized to survey the general state of wastewater. The darkening of wastewater is regularly because of the development of different sulfides, especially, FeS [7]. Generally, dairy wastewater is white or yellow in colour [14]. The pH is quantified as the negative logarithm of the hydrogen particle fixation. Its range is given between 0 to 14; under 7 being acidic and more than 7 is considered basic. The wide portrayal in the pH estimation of gushing can influence the rate of organic response and survival of different microorganisms [7]. Milk possesses alkalinity but sometimes it becomes acidic during the fermentation process in which the lactose from the milk is converted to lactic acid [14]. The environmental condition like temperature also plays a major role in creating impacts in the dairy ingredients and also the natural radiations occurring in water for a living being occupying oceanic media. It relies on the season, time inspecting, and so on. The water temperature assumes an essential part in affecting the wealth of phytoplankton. The water released from the dairy industry, which has higher temperature, influences the land unfavourably. The temperature of wastewater may extend from 26.2–35.4°C [7]. BOD is characterized as the measure of oxygen required by a microorganism to degrade the complicated organic compounds and converting it into simpler compounds. During the degradation process, the oxidation of natural toxins takes place and it is converted into carbon dioxide (CO_2) and water (H_2O) with the support of microorganisms consequently bringing down the measure of BOD [7]. The COD test decides the oxygen required for concoction oxidation of natural issue without the assistance of solid synthetic oxidant. COD is a test, which is utilized to quantify contamination of residential and modern waste. The waste is estimated as far as the nature of oxygen required for oxidation of natural issue to deliver CO_2 and H_2O [17].

The total suspended solids (TSS) are the total volume of organic matter present in the dairy wastewater in the suspended form. The TSS formed during the curd making sector and it mainly consists of the cheese whey in it [14]. Dairy wastewater consists of the immense amount of nutrients in the effluents. The dairy effluent remains as one of the major cause for water pollution in several regions because of the presence of enormous amount of organic loading which is the best food source for micro organisms such as bacteria, algae and fungi [25]. The chemical composition of some the dairy effluents is described in the Table 1.

1.1.2. Environmental effects of dairy wastewater

The dairy effluents are mainly composed of several components such as organic, inorganic, nutrients, suspended and several solid components. These components present in dairy effluents are responsible for the bad odor and turbidity of the wastewater [20]. The processing steps involved in the manufacture of dairy products include water consuming divisions such as tanks, cleaning storehouses, warm exchangers, channels and homogenizers give rise to a lot of effluents with a high organic waste composition. Basically, the effluents gushing out of all the above units produces wastewater with high organic load constituted by the high amount of COD, BOD, P, N, FOG [26]. The organic wastewater eliminated from the dairy industries is highly harmful to the ecosystem when compared to the other toxic gaseous and solid waste. The organic waste rushed into the fresh water sources damages the features of the water in all aspects and it becomes one of the considerable producers of wastewater when compared to other industries [24]. The processing and manufacturing sectors of the dairy industry devour a generous amount of fresh water and it also produces a large amount of wastewater containing enormous organic and nutrient materials as waste. It is necessary to treat the dairy wastewater before disposal. Feasible water and wastewater management were administered to enhance the quality of the wastewater and some efficient techniques are employed in the manufacturing process to lessen the consumption of freshwater [27]. The dairy waste on increased organic con-

Table 1
Characteristics of some of the dairy effluents released from the industrial sources

Wastewater type	pH	BOD (mg/ L)	COD (mg/ L)	TSS (mg/ L)	TDS (mg/ L)	Reference
Raw wastewater	5.5–7.5	350–600	1500–3000	250–600	800–1200	[6]
Whey waste	4.1	20000	71526	22050	–	[103]
Milk industrial wastewater	11.70	3000–8910	5000–14250	1420–3540	–	[34]
Aavin dairy industry washwater	6.4–7.1	–	2500–3300	630–730	–	[106]
Raw wastewater	7.1	2800	5000	–	–	[22]
Dairy waste	7.2–8.8	1200–1800	1900–2700	500–740	–	[78]
Dairy effluent	5.5–10.5	200–3500	2–2.5	–	–	[19]
Cheese whey waste	–	–	68814	–	–	[107]
Dairy effluent	6.07–7.10	–	1402.8–2133.8	–	–	[108]
Dairy effluents		980–7500	680–4500	–	–	[109]
Cheese waste	4–12	300–1400	650–3000	250–2700	–	[11]
Cheese whey	5.5–6.5	–	45000–72000	–	–	[61]

centration becomes noxious to the living organisms such as fish, aquatic plants and algae present in the water sources [20]. Dairy effluents are composed of complicated organic mixtures. During the decomposition of nutrient components present in the dairy effluents, the volume of the dissolved O_2 gets lowered leading to an anaerobic environment in the water sources. The emission of highly noxious odor from the dairy effluents is one of the major hindrance for the public residing near the water sources. The freshwater sources which are contaminated by the dairy waste becomes one of the major birth places for several insects and pests, furthermore, due to its stagnant nature it acts as a major breeding region for mosquitoes which are causing several harmful diseases such as chickenguniya, dengue, malaria, yellow fever, etc. The casein is one of the main compound eliminated from the dairy industry and when the casein is subjected to degradation it is converted into a highly foul-smelling black colored waste. This black colored sludge is harmful to the aquatic inhabitants and it causes the death of aquatic organisms [20]. The contamination caused due to the industrial effluents ruins the fishing business, creates a shortage of fresh water and causes harmful diseases [28]. The dairy effluents when blended with the fresh water sources cause hormonal disorders in the aquatic lives and human beings [29]. The ecological effect of dairy effluents can be high, particularly because of the extensive release of waste waters which contain high natural issues and different supplements including N and P. The release of dairy plant effluents to the water assets can prompt annihilation of sea-going life and other marine animals, which can provide more nourishment for microbial consortia and bring on additional O_2 consumption.

1.2. Dairy waste water treatment

The dairy industries manufacture various products such as milk, spread, yogurt, etc. and consume an immense amount of water. In addition, it also produces a large quantity of wastewater with elevated levels of organic loading and it is mandatory to eliminate this organic waste before being discharged. Dairy wastes are easily prone to contamination and it gives a bad odour on degradation which creates a major nuisance to the nearby living beings and it may also contain pathogens emitted from the contaminated materials [20]. The dairy industry processed water such as rinse water and white waters released during the production mechanism bestow greatly to the large amount of dairy effluent released into the environment [30]. The degradation of the dairy effluent is complex and along with the mechanical and physico-chemical techniques the biological treatment enhances the deterioration of this organic waste [31]. The technologies used for degrading the dairy wastewater must be selected according to various process parameters and energy consumption is one of the main factors to be considered during the designing of treatment technology [32]. Water recovery during the sustenance preparing part especially in the dairy industry should be painstakingly investigated since there is a high danger of potential defilement of the dairy items with the treated wastewater [33]. Be that as it may, a few issues have been found during the wastewater treatment of dairy effluents such as low sludge settle ability, issues in the corruption of fatty substance, low protection to stun loads and challenges in the expulsion of supplements such as N and P [36]. The dairy wastewater should be pre-treated before subjecting to the wastewater treatment plant to enhance the remediation efficiency. Initially, the wastewater is screened physically for removing the solid particles and dust particles present in the effluents released from the industry using grit chambers and wire screens. Then, the pH of the wastewater is determined and certain pH adjustments are done to the wastewater so that it can be directed to the correct treatment plant according to their alkalinity. Furthermore, the FOG present in the wastewater become a great hindrance during the effluent treatment and so it is necessary to remove them from the wastewater. The FOG are treated and removed using floatation, gravity traps and hydrolyzing using enzymes [17]. A few natural treatment frameworks including oxygen-consuming and anaerobic forms have been utilized for dairy wastewater treatment. Notwithstanding, every one of these frameworks has its own particular inconveniences caused by either high vitality necessity or solid operational trouble [37].

1.2.1. Biological treatment method of dairy wastewater

The biological method is a critical and necessary part of any wastewater treatment plant that remediates wastewater from various sectors and it also helps in reducing the harmful impact of wastewater on the environment. This method seems to be a propitious method of treating wastewater with high organic content. This method uses microbes for degrading the high organic loading and other toxic chemical substances [19]. It is basically divided into two types such as an aerobic and anaerobic method. The deterioration of organic compounds in the wastewater using microbes in the presence of oxygen is known as an aerobic treatment method [14]. The success of a biological treatment unit depends on two factors such as the ability of the microbes in the system to degrade the organic loading present in the effluent and the competence of the solid-fluid detachment of the biomass at the last phase of the treatment strategy [38]. Most dairy handling plant squanders react to the biological treatment in light of the fact that the predominant natural materials in such squanders are fat, lactose, and protein, which are promptly debased by oxygen-consuming microorganisms [39]. Basically, the effluents from a dairy industry are composed of elevated levels of COD, BOD and other organic compounds. These parameters in the dairy waste can be lowered effectively by biological treatment. Biological treatment offers a cost-effective technique for dairy effluents and the treatment techniques are getting upgraded day by day [34]. The variation in the different parameters of the contaminants present in the dairy wastewater makes it difficult to be treated, so it should be assessed on an individual plant premise [39].

1.2.2. Aerobic treatment of dairy wastewater

Aerobic treatment is the treatment of wastewater in the presence of oxygen, while anaerobic is without oxygen. These two terms are straightforwardly identified with the sort of microbes or microorganisms that are engaged with the debasement of natural polluting contaminants in a given wastewater. Accordingly, high-impact treatment forms occur with only in the sight of air and the microbes utilize this air to acclimatize organic contaminants which are then converted to CO_2, H_2O and biomass. The natural treatment is comprised of the oxygen-consuming aerobic and oxygen starving anaerobic process. The aerobic treatment of dairy wastewater is used for the diminishing of BOD and it is also utilized for the evacuation of organic supplements such as P and N. In the aerobic treatment, the wastewater is subjected to an oxidation reaction in the presence of oxygen which leads to the deterioration of harmful microorganisms residing in the diary industrial effluent [14]. The aerobic treatment is commonly distinguished into two processes such as suspended growth processes and attached growth processes. Conventionally, many aerobic treatment methods such as aerated lagoons, oxidation pond, and activated sludge process (ASP) are effectively used for treating the organic industrial effluents [40]. Even though the aerobic treatment seemed to be one of the efficient method to treat dairy waste, the control of the air circulation administrations becomes a key issue [41].

1.2.3. Aerobic lagoons

Aerated lagoons are one of the finest technologies practiced for the treatment of dairy wastewater and it works as a competent and easy strategy for evacuating the organic and inorganic loading in the dairy effluents [42]. Lagoons are one of the well-known treatment system used in the treatment of dairy wastewater. In the beginning, it is used to stock and treat animal waste in some parts of the world. The lagoons can be operated both in aerobic and anaerobic condition depending on the type of wastewater released from the industry. The schematic diagram of the aerobic lagoon is illustrated in Fig. 1 [17]. The cost-effectiveness and their efficient activity have made the aerobic lagoons a suitable technique for treating the dairy effluents in many developing nations [42].

Many researchers have stated that the lagoons can be efficiently used to lower the concentration of the nutrients and organic compounds in the industrial effluents. NH_3 is the major compound of nitrogen present in the aerated lagoons which complicate the effluent treatment [43]. Microorganisms residing in the aerated lagoons are mainly responsible for the degradation of the organic and inorganic substrates present in the effluents. Bacteria is another major category of prokaryotes present in the lagoons and they highly support the degradation of the organic loading composed in the effluent. Several varieties of bacteria are involved in the functioning of the aerated lagoons. They help in converting the complicated organic and inorganic compounds into simple compounds which are easily degradable [12]. The design and the functioning of the aerated lagoons are enhanced by understanding the different parameters of the microorganisms such as type, structure, morphology and nutrient uptake rate of the microorganisms [12]. Temperature is considered one of the important criteria in the execution of aerobic lagoons because of its great impact on the metabolism of the microorganisms living in the lagoons [42]. The efficacy of the aerated lagoons mainly depends on the type of living organisms acclimatized in the lagoon and their nutrient uptake rate [12]. The maintenance of the removal efficiency of the aerated lagoons is bit difficult as it mainly depends on the characteristics of the microorganisms, to enhance the performance of the aerated lagoons many new advancements have been implemented in the lagoon system for the efficient elimination of the toxic pollutants in the dairy effluents. Some of the aquatic plants such as water hyacinth and duckweed are subjected to the lagoon system for removing the elevated amount of nutrient and organic loading [44]. The implementation of duckweeds in the aerated lagoons seemed to increase the removal of the organic content composed in the dairy effluents. The elevated concentration of the nutrients such as N and P in the dairy effluents leads to eutrophication in the lagoons. The average amount of N and P recovered from the effluents using duckweed wetlands are seemed to be in the range of 22.4 $gN/m^2/y$ and 7.4 $g P/m^2/y$ [43]. Luo et al. [44] have conducted a study on removal of nitrogen using Myriophyllum aquaticum in a three stage pilot scale surface flow constructed wetlands. The nitrogen removal efficiency was determined to be 87.7–97.9%, whereas the total nitrogen content was obtained to be 85.4–96.1%. The hazardous diseases caused due to the waterborne viral contaminations is one of the biggest limitations of the aerated lagoon system and so to prevent the disease outbreaking from the lagoons several precautions should be taken by the people working near the pond and also the lagoons should be maintained in a perfect condition [45].

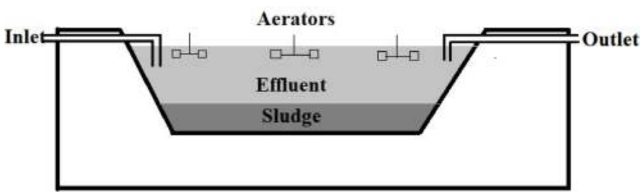

Fig. 1. Schematic representation of aerated lagoons [17].

1.2.4. Trickling filters

There has been a developing enthusiasm for the use of trickling filters for the high-impact treatment of industrial waste waters [46]. Basically, in the trickling filters, the wastewater is implemented on the biofilms developed on the surface of the medium and the microorganisms residing in the biofilms consumes the organic compound in the waste waters leading to degradation of complicated organic substances in the dairy effluents. The trickling filters are not immersed into any medium the wastewater is subjected into the media through the sprayers and this system is especially used to degrade the wastewater with high organic and nutrient content [47]. The diagrammatic representation of the trickling filter is shown in Fig. 2 [17]. This system is composed of a supporting medium along with microorganisms with the provision for air circulation and sprayer for distributing the wastewater [48]. Due to technological advancement various materials are used as media for the growth of the microorganisms. Usually, the media are arranged in distinct types such as vertical, tubular and cross flow paths. The media is packed with greater surface area, high void fraction and greater permeability [47]. The

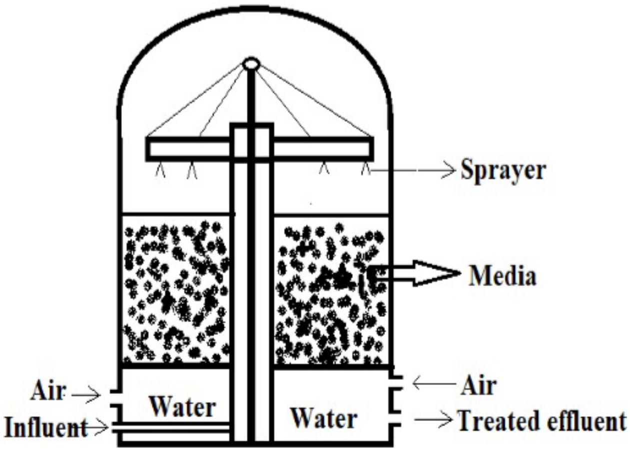

Fig. 2. Schematic representation of trickling filters [17].

efficiency of the trickling filter depends on the parameters such as pH, temperature, volume of biomass, growth rate of microorganisms, nutrient uptake and removal rate. The trickling filter is known for removal of nutrients and nitrogen sources [49].

The wastewater with elevated levels of TSS, COD, and BOD are treated using the trickling filters. In this method the dairy effluents are subjected to the supporting media covered by the biofilm and the organic wastes present in the wastewater are consumed by the microorganisms present in the biofilms. The media is generally packed using various materials such as rocks, plastic, foam, etc., [48]. The treatment of dairy wastewater using trickling filters is seemed to be highly preferable due to its cost-effectiveness. The lava rock is used as a supporting medium in the trickling filter and it aids in cleaning the waste compounds. The media used in the trickling filters are selected based on some of the parameters such as less weight, cost effectiveness, high strength, high shock resistance, high corrosive resistance, elevated porosity and large surface area. The microorganisms consume the vital nutrients such as C, H, K and P; furthermore, it also contains a small number of other elements. The organic loading present in the effluents is transferred to the biofilms. The trickling filter column is also packed with another cost efficient cheaper materials such as wood wastes, peat, compost and ceramic. The consumption of wastewater increases the microbial population leading to degradation of complicated organic substances [49]. In the study conducted by Raj and Murthy [46] a cross flow medium trickling filter utilized in the dairy wastewater treatment resulted in a higher COD elimination of about 1.94 kg m^{-3} d^{-1} at a hydraulic loading rate of about 17 m^3 m^{-2}. Mehrdadi et al. [48] have investigated the efficiency of trickling filter on dairy wastewater and the results showed that the microorganism present in the media biofilms effectively eliminate COD of about 2.750 mg/L.

1.2.5. Activated sludge process

Activated sludge process (ASP) is a highly preferred method for treating the waste waters with organic and inorganic loading; henceforth it is highly used in treating the household and sewage waste waters. It is highly preferred for the removal of carbon, nitrogen and ammonia compounds present in the dairy wastewater [42]. The schematic representation of the ASP is shown in Fig. 3 [17]. ASP is one of the highly preferred method for treating the dairy effluents due to its ability to remove and treat nutrients present in the effluents [50].

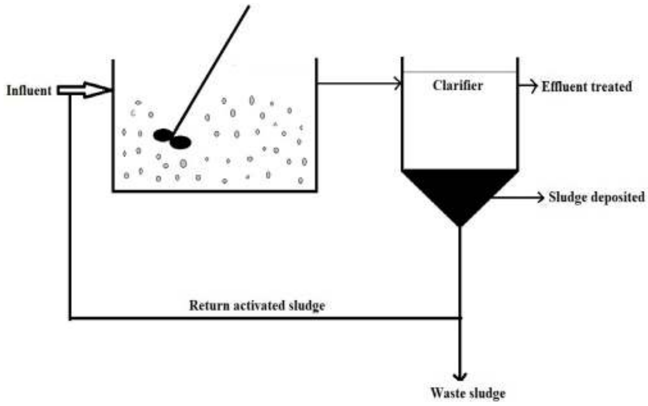

Fig. 3. Diagrammatic representation of activated sludge process [17].

Microbes and protozoa are main ingredients of activated sludge process which helps in degradation of nutrients and organic substances composed in the wastewater. These microbes consume the suspended organic waste substances present in the wastewater and it converts them into an activated sludge which is later on removed and recycled. The understanding about the microbial groups and their relationship with these organic substances and biological wastewater treatment is needed to quickly screen and survey process exhibitions and to enhance the organic procedures happening in wastewater treatment plants. Protozoa populaces assume a noteworthy part in the microbial sustenance networks amid the organic treatment in wastewater treatment plants, Furthermore; they are generally utilized as a marker of actuated muck plant execution [41]. Activated sludge treatment is an effective aerobic used in the biodegradation of organic components present in the dairy wastewater. In this method, the wastewater is passed into a tank provided with aeration and further the activated sludge is removed from the wastewater using a clarifier giving out a clarified wastewater [51]. This system is also highly effective in the degradation of complicated substances such as protein, lactose, fats and oils using the microorganisms [41]. The ASP coalesced with the membrane reactor seems to be an effective system for treating dairy wastewater. This system has shown great execution for the expulsion of organic matter from the dairy wastewater [52]. The optimization and determination of process coefficients are essential in designing an efficient activated sludge system. The ASP with 5 d of incubation period along with maintenance of BOD at 95% shows an effective removal of organic compounds from dairy effluents. This system functions beneficially in the pH range of about 9–10.5 [53]. Activated granular sludge is a notable advancement in the ASP, furthermore, in this method a set of the novel microbial group works on the expulsion of C, N, P and different organic compounds present in the effluent. The granular sludge system is entirely different from the activated sludge system in all aspects such as its morphological, chemical and biological properties. This system is well suited for cost effective treatment of the dairy wastewater and it shows an efficient removal of every nutrient and organic compounds present in the dairy effluents [54]. The aerobic granular sludge treatment is efficient than the normal activated sludge system due to its strong resistance against shocks, elevated settle ability, less toxicity and higher biomass recovery [55]. The aerobic granular sludge system is used to treat the industrial effluent containing around 100–1000 mg L^{-1} of suspended solids in the effluent. As the dairy industry is composed of a large number of suspended solids, aerobic granular sludge system is implemented for the treatment of the dairy effluent [56]. Activated sludge system is used to treat the wastewater with elevated levels of organic content and it showed pretty good removal efficiency in eliminating the waste waters with high COD, BOD, N, P and other nutrient compounds [57]. In the treatment of dairy wastewater using ASP conducted by Nasr and El-Kamah [28] the results concluded that nearly 64–96% of volatile organic compounds (VOC) correspondingly.

1.2.6. Rotating biological contactors (RBC)

Rotating biological contactors (RBC) was initially used in the year 1900 using wooden racks as the discs. Later on, the polystyrene material was used as the discs in 1958 and remarkable advancement have been made in the design of the RBC. It primarily works on the adsorption principle and it is generally used in the treatment of several industrial and household waste waters [58]. RBC are highly preferred treatment system for removing the nitrogen compounds from the industrial effluents [48]. In specific, the wastewater possessing higher BOD and COD is treated using the RBC. The diagrammatic representation of RBC is viewed in Fig. 4 [61]. RBC system is widely preferred than other treatment system due to its high removal efficiency and less energy consumption. It is an attached growth reactor includes a set of circular discs rotating in a circular way in which basically the discs are made up of plastic. The rotating discs with microorganisms feed on the nutrients and organic matter in the water. Aeration is also provided to enhance the growth of the microorganism in a strong way [58]. RBC is one of the well-known systems for its cost-effectiveness and higher shock resistance.

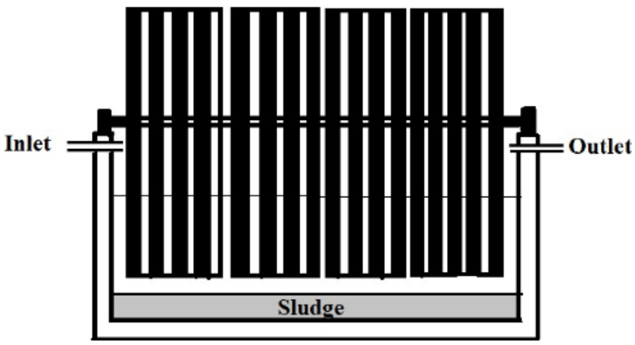

Fig 4. Schematic representation of rotating biological contactors [61].

Usually, the rotating discs are immersed in the dairy effluents containing organic content and the surface of the disc covered with the biofilm layer containing microorganisms. The discs with the biofilm layer are submerged into the effluents and rotated serially. This further leads to the degradation of the organic content by the microorganism present in the discs causing reduction of the organic and nitrogen content. The microorganisms in the biofilm consume the organic and nutrient compound leading to the increase in the volume of biomass. The biofilm layer slowly gets thickened and increases in volume. The thickened sludge falls from the discs and gets segregated in the sludge digester where it is converted into water and gas [59].

In RBC, the gaseous O_2 is exchanged to the fluid film in the part presented to air. This broke up gas at that point diffuses to the biomass where it is expended alongside the natural aggravates that also circulates into the biofilm. Amid the submerged stage, the fluid film is incompletely peeled off and it blends with the mass fluid as the circle leaves the fluid pool [60]. Around 40–45% of the disc is submerged into the dairy effluents with a suitable contact time. The rotating discs are rotated in a correct speed without disturbing the biofilm attached on the disc. The rotation of the disc helps in bringing out the relationship between the air and water, furthermore, the water rising due to the rotation of the disc are brought back to the container. The cyclic rotation of RBC paves the way for the biofilm to consume all the organic substances present in the wastewater through which the nutrients and organic matter get diffused into the biofilm layer [61]. RBC is a natural technique to deteriorate the organic issue by acquiring it adequate contact of air. It offers an elective innovation to traditional actuated slop process in light of its straightforwardness to keep up and work, having high process security with less space prerequisite. RBC framework ends up being temperate as tertiary evacuation isn't required [60]. The RBC are highly preferred for several effluent treatments due to its features such as larger surface, less energy consumption, cost-effectiveness, easy construction, less shock, less maintenance and easily operatability. Much technological advancement has been made in the RBC and it becomes one of the main treatment systems in the aerobic treatment of wastewater [61]. RBC have shown higher removal efficiency than other treatment due to its compatibility and greater reaction rate [62]. Kadu et al. [63] have investigated the dairy effluent treatment utilizing the three-stage rotating biological contactor. The results of this study concluded that higher BOD, COD and TSS removal efficiency of about 96%, 80% and 79% is obtained at a rotational speed of 8 rpm. The energy consumption in the RBC is nearly equal to the extended aeration activated sludge process. Nearly 50% of the organic content present in the dairy effluents are removed during the initial stage of the RBC unit itself [63]. Ebrahimi and Asadi [61] have investigated the treatment of dairy effluent using three stage BC resulting in a greater COD removal efficiency of about 80–83% is obtained for an HRT of 16–24 h. In this study the higher COD removal efficiency of 92% was seemed to be elevating with the increase in HRT level.

1.2.7. Sequencing batch reactor

Sequencing batch reactor (SBR) is a time specified reactor system and it functions in a serial mode repeatedly. The five stages of the SBR are filled, react, settle, decant and idle, furthermore, the SBR works repeatedly in these five stages in a cyclic manner [64]. SBR seems to be the most promising technology for the treatment of dairy wastewater. It is a 'fill and draw' activated sludge system. The schematic representation of the sequential batch reactor is viewed in Fig. 5 [17]. In this system, wastewater is added to a single batch reactor, treated to remove undesirable components, and then discharged.

Equalization, aeration, and clarification can all be achieved using a single-batch reactor. SBR is one of the auspicious methods used for treating the effluents from the dairy industry [39]. Basically, the SBR works under the principle of activated sludge system. The SBR has shown a successful execution sequestration of N, C, P, etc. Moreover, the procedure followed in the SBR permits impersonating of numerous procedures in traditional consistent stream reactors and can yield unrivaled execution [34].

The wastewater with high total solid concentration is treated effectively with the help of the SBR system due to its efficiency in lowering the suspended solids concentration and cost-effectiveness [65]. The efficiency of the SBR system depends on the parameters such as volume of dissolved O_2, retention time, HRT, composition of organic load, COD, nutrient composition, denitrification and nitrification rate. It is a compatible treatment system for many industrial effluents due to its simple construction and efficiency [64]. The dairy wastewater containing high organic compounds can be effectively treated in an aerobic granular sludge SBR. The granular sludge is an important parameter which the biomass retention is higher than other process because the granular sludge settles down faster than activated sludge particles. The particulate components present in the dairy wastewater are adsorbed on the granules and they are degraded in the SBR cycle [38]. The SBR system has defeated numerous hindrances and furthermore contrasts from other treatment technologies. The SBR has shown satisfactory results in treating the dairy wastewater with different convergences of COD, BOD, TSS and other

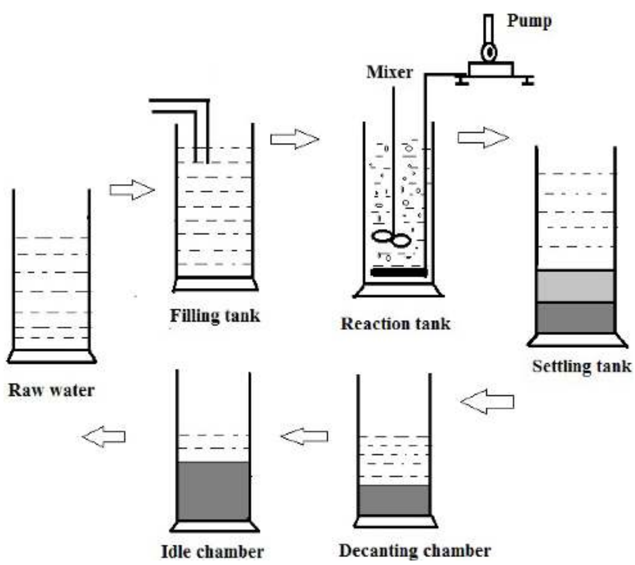

Fig 5. Schematic representation of sequencing batch reactor [17].

organic loading content [34]. Dairy effluent using the SBR has showed decreased levels of suspended solids. Furthermore, the cumulative treatment efficiency of SBR in treating dairy effluents was found to be 90.8% for TSS, 86.5% for BOD, 78.5% for COD, thus, the SBR is found to be highly effective in managing the dairy wastewater [39]. The SBR is preferred over other treatment technologies due to the features such as simple activity, easy in handling water inconstancy, minimal effort, no requirement for settling tank and high removal efficiency of TS [65]. Abdulgader et al. [34] have investigated the treatment of dairy wastewater using sequencing batch flexible fibre biofilm reactor. In this work, high COD parameters removal efficiency of about 89.7% and 97% have been reported. Bae et al., [52] have investigated the elimination of nutrient using membrane separation process combined with an SBR. The results showed that higher BOD removal of about 97–98% is obtained using the membrane and rest of the nutrients such as N and Pare excluded at a removal efficiency of 80% using SBR. Mohseni-Bandpi and Bazari [65] have investigated the treatment of industrial dairy wastewater using SBR. In this study, a higher COD removal efficiency of more than 90% is achieved with a COD concentration of about 400–2500 mg L^{-1}.

2. Anaerobic treatment of dairy wastewater

Even though there are some upsides of the aerobic method, there are some downsides involved in these studies. The major drawback in the aerobic treatment is utilization of high energy through aeration, less efficient due to the enormous growth of microbes [66]. Anaerobic treatment is the supportive method for treating organic constituents in the dairy wastewater due their notable advantages. Anaerobic treatment of dairy waste waters is a complex process that degrades the organic matter by the variety of intermediates and utilizes microbial consortium in the absence of oxygen. It is an important approach in the reduction of pollution and waste [67]. This type of treatment is considered to be an excellent process by several researchers when compared with the aerobic process [68]. Degradation and stabilization steps are involved in the anaerobic digestion process which uses microbes under anaerobic conditions [69]. The types of microorganisms involved in the anaerobic degradation are mixed cultures of acidogenic and methanogenic bacteria which have varieties of optimal environmental conditions. Providing best environmental parameters for the entire microbial group is troublesome. Hence improvement of ideal conditions for the methanogenic bacteria contributes prosperous operation of anaerobic degradation. A few elements including pH, temperature, organic loading rate (OLR), HRT, C/N ratio, presence of inhibitory issues and reactor arrangement may influence the execution of anaerobic systems [23,70]. The anaerobic process has attained high relevance, since renewable energy can be produced through the biological treatment of dairy wastewater [71]. Mostly maximum percentage of high strength organic load gets changed into inert biological cells, CO_2 and the rest is used for cell development. For natural stabilization of dairy wastes, anaerobic systems are observed as more economical because of low energy requirement in these systems. Besides generation of sludge is low when compared with the aerobic systems and utilize high content of organic waste for energy generation [72]. Terrible flavours are away if the framework is worked productively. Anaerobic treatment assimilations have been perceived by the United Nations improvement program as one of the better valuable source of energy supply due to their less capital investment. For the past two decades, various anaerobic reactors have been designed in order to employ various routes of holding up the biomass within the rectors [73]. Different sorts of anaerobic digesters were utilized as a part of research facilities to treat dairy waste waters for example, anaerobic filters, up flow anaerobic sludge blanket reactors [74], anaerobic packed bed, anaerobic contact digesters and anaerobic fluidized bed reactors and so on [75]. Since this biochemical process occurs by the consortium of microorganisms, their population levels and their types gets affected easily due to the interruption in system which directly affects the performance of reactors. The most important factors of anaerobic reactors are sludge retention and mass transfer which helps to achieve best efficiency in the wastewater treatment [76]. The anaerobic reactors retain highly active biomass that enhances the contact between the waste and biomass. Thus the high rate anaerobic reactors hold up the biomass for longer time than the HRT [77]. These anaerobic reactors have several upsides than the aerobic like quick start up with less issues, capacity to resist shock, need of low inorganic nutrients, capacity to adjust discontinuous feeding, use of unsophisticated instruments, low energy requirements, low operational and capital costs and velocity of restart after long close down periods [78–81]. The operational expenditure and capital expenditure of aerobic ad anaerobic reactors are explained in Table 2. This table shows that more number of anaerobic reactors have less OPEX and CAPEX when compared with aerobic reactors.

Anaerobic reactors generates biogas like CH_4 and CO_2 [82] and helps to transfer these gases to the other process which are the additional advantages of anaerobic digestion process. For the past few years the application of anaerobic treatment has been raised in treating high quality wastewater with less energy requirement and a by-product production like biogas. Nowadays, the researchers have been showed their interest towards anaerobic digestion because this process emits some nutrients which can be recycled and used as bio-fertilizer in the agriculture [66]. Several studies were reported in this paper regarding the treatment of dairy wastewater using different types of anaerobic reactors.

2.1. Anaerobic filters

Anaerobic filters (AF) are a delegate connected development process that has been broadly connected to the treatment of varied waste waters. The major type of anaerobic digestion process applied for the treatment of dairy wastewater is anaerobic filters. It is the most prevalent method for treating low strength wastewater and it is limited for high strength wastewater due to the high OLR [23]. Fig. 6. represents the simplified diagram of anaerobic filter [14]. AF among the anaerobic procedures emerges as an appealing choice. The presence of filter media and their stability in the anaerobic filters act as a physical obstacle across the biomass [67]. It contain at least two filtration chambers in their arrangement. In the AF, the organic material present in the wastewater gets degraded by the biomass and then adhered to the exterior of the filter material and additionally these anaerobic filters are broadly utilized as an optional treatment to enhance the solid removal. Utilizing suitable packing media is vital to the AF because the physical and chemical characteristics of the media have critical effect on the biomass and its reactor performance.

AF are packed with different packing materials to hold up the microbes in the voids. The activated microbes in the filters make the reactor to perform with the high OLR wastewater. Perfect packing media expands the surface area and in addition porosity. An expansive surface zone of the media improves the biomass connection and expanded porosity diminishes the general reactor volume, and additionally limits obstructing of channel. Based on the supporting material in the anaerobic reactors, the removal of organic materials from the dairy wastewater takes place. The anaerobic filters have been directed by utilizing different materials like seashell, charcoal, plastic materials, ceramic, sintered glass, and characteristic stones like limestone, rocks, pumice, clay and so on [23]. Some researchers applied anaerobic filters in treating fruit canning and cheese

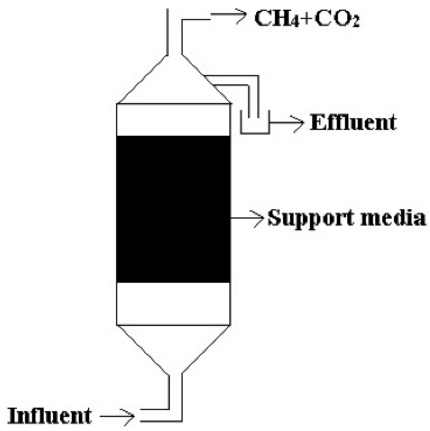

Fig. 6. Diagrammatic representation of anearobic filters [14].

Table 2
CAPEX and OPEX comparison of different bioreactors [72]

Treatment technique	CAPEX	OPEX	Merits and demerits
Lagoons	Low	Low	Good resistance to hydraulic and organic shock loads
Anaerobic fluidized bed bioreactor	Low	–	Low reactor volumes
Upflow anaerobic sludge blanket	Low	Low	Requirement of energy is low
Membrane bioreactor	High	High	Fouling

dairy waste waters [73]. They observed that 80% COD removal efficiency was achieved in these waste waters with the maximum OLR of 19 and 17 g COD $L^{-1}d^{-1}$. Nowadays, several researchers have been focussed on the utilization of industrial by-products in the anaerobic filters for natural possible applications [83]. Jo et al. [84] study explained that cheese whey and other substrates can be effectively treated by the anaerobic filters which was packed with blast furnace slag (BFS) obtained from the iron ore processing. In this experiment, they showed best COD removal of about 80% OLRs of 0.8–2.4 g COD per day. Additionally, kinetic studies also conducted for understanding the reactor system. Anaerobic filters have different impediments like minimum reduction of nutrients, necessities of further treatment of sludge and effluent. It was accounted be alternative growth treatment process for high quality effluent.

2.2. *Up flow anaerobic sludge blanket (UASB)*

In these current years, the utilization of up flow anaerobic sludge blanket has increased tremendous popularity which is the most commonly used anaerobic reactors for the treatment of waste waters containing organic waste [85]. The schematic diagram of UASB reactor is illustrated in Fig. 7. In 1970s, the unpacked reactor called UASB was introduced for the treatment of wastewater. This reactor has better settling characteristics because the sludge does not undergo mechanical agitation. Appropriate mixing takes place in UASB due to the flow distribution that occurs with high velocity and through agitation it leads to gas production. Some of the components of UASB reactors are gas-solid separator, influent entry system, effluent exit system and sludge blanket [82]. This reactor is steady and vigorously process effective. When there is a need of cost reliable method for the wastewater treatment, UASB plays a major role. High volume of wastewater can be treated in UASB which is found to be major upside of this anaerobic reactor [86]. In this reactor, the wastewater flows upward and the cell gets held in the reactor due to the sludge settlement within the reactor [87]. It converts the availability of chemical energy in wastewater into value added products and soluble organics [88]. In a solitary reactor, UASB consolidates the entire procedure of processing and settlement so that the impression gets reduced. The conventional anaerobic treatment process like UASB was applied for the treatment of dairy wastewater. Vlyssides et al. [89] investigated dairy wastewater using UASB reactor. This study interpreted that this anaerobic digester was satisfactory due to the reduction of 90% COD in the dairy wastewater. Additionally, it also demonstrated that the proposed innovation could be supportable not just as far as the treatment of cheese dairy wastewater yet for their energy usage too [89].

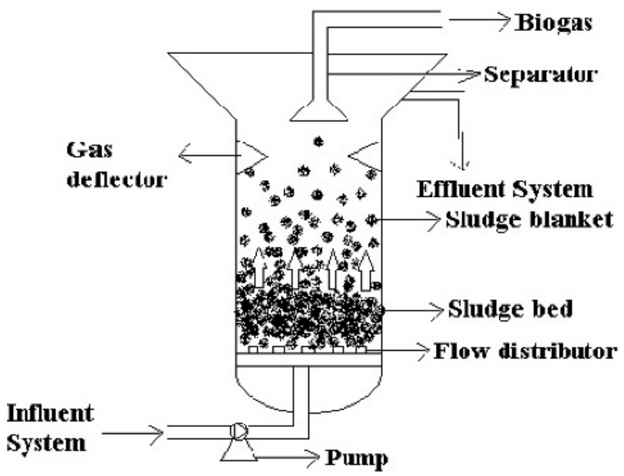

Fig. 7. Schematic representation of up-flow anaerobic sludge blanket reactor (UASB) [85].

A newly modified UASB reactor was designed with scum extraction device and lamella settler by some authors [90] for the effective treatment of dairy wastewater. In this study, they proposed that this system requires only fewer processing units and operational costs. They also depicted that modified UASB produces high volume efficiency and lamella settler is more effeicient than the traditional method like dissolved air flotation (DAF). In this new framework generation of chemicals and energy consumption like traditional approach are kept away [90]. Gotmare et al. [91] used UASB for treating organic loaded dairy wastewater and analysed its performance through monitoring pH, COD, BOD, TSS and volatile fatty acids (VFA) and biogas production. The reactor accomplished COD, BOD, TSS evacuation proficiency was seen to be 87.06%, 94.50%, and 56.54% separately and VFA varies with the ratio 0.28–0.43. The overall CH_4 synthesis was observed to be 75% of the biogas [91]. In spite of the fact that UASB has been noted for the focal points in the ability of CH_4 generation, low operational costs, high toxin evacuation efficiencies and least creation of sludge, its treatment productivity and its achievement is unsuitable [92]. A study has been focussed on the performance of UASB for treating the high fat content (1200 mg/L of FOG) of dairy wastewater. They also evaluated the characterization of different biomass and concluded that this reactor showed high COD removal rates of about 89–95% [93]. Rico et al. [94] proposed a co-digestion process which consists of UASB with a settler and water conversion framework. 95.1% COD removal and a volumetric CH_4 production rate of 9.5 $m^3 CH_4$ $m^{-3} d^{-1}$ was obtained through this co-digestion process. They described that this method reduces stability issues which occurs by the alkalinity and this proposed technology are more suitable for polluting environment with cheese whey [94]. Table 3 depicts the COD removal obtained from various research articles which illustrates the performance of UASB reactors. The sludge production also takes place in

Table 3
COD removal from the dairy waste using UASB reactors

UASB reactor quantity (L)	Feed COD	COD removal	References
31.7	700–1200 mg/L	55–93%	[110]
12.85	500–4000 mg/L	96.3%	[111]
8	19.4 Kg/ m^3 d	95.1%	[94]
10	4056 mg/L	79.4–85.5%	[111]
1.5	700 mg/L	90%	[93]
6.6	500–3300 mg/L	67%	[112]
120	1000–2000 mg/L	95%	[18]

the UASB with the organic and inorganic constituents along with the microorganisms. Another drawback is that higher concentration of solid content in the dairy wastewater also affects the performance of the UASB.

2.3. Continuous stirred tank reactor

It is widely practiced in the laboratory studies than the full scale treatment because of its HRT limitation. Continuous stirred tank reactors are applied in treating synthetic and diluted dairy wastewater [95]. Fig. 8 represents the schematic picture of continuous stirred tank reactor (CSTR). Nowadays researchers have been focussed on this reactor for the degradation of organic matter and high methane yield [96].

They used four types of laboratory scale CSTR. The total reactor volume is 15 L and 10 L of head space. About 477% the CH_4 production was raised in per unit reactor volume and additionally (OLR) was increased from 1.83 to 5.04 g VS L^{-1} day^{-1}. But CSTR are finite to the full scale treatment because of its limitation in HRT. Table 4 represents different experimental conditions used in CSTR for the treatment of wastewater. Another investigation was carried out by the researchers to identify the treatment limits in feed rate and OLRs in continuous stirred tank reactor [97]. From the result they have analysed that the complications in anaerobic digestion of cheese whey can be settles out by the co-digesting with liquid dairy manure. The reliable process operation was achieved in the reactor after 7–8 D of HRT.

2.4. Anaerobic contact process (ACP)

It is similar to the anaerobic activated sludge process included with completely mixed anaerobic reactor taken after by some type of biomass separator. ACP depicts the contact between high biomass concentration and small reactor [14]. The return of extra sludge to the reactor enhances the high contact between biomass and waste which is the major benefit of the anaerobic contact process. So, high efficiency can be obtained from the recycling of sludge. Due to the anaerobic bacteria, gas formation occurs which leads to the poor sludge settlement which is found to be drawback of ACP in dairy wastewater treatment. The generation of gas in ACP can be limited by applying vacuum degasification and thermal shock before the settler [98]. Though the ACP was found to be simpler in concept than the other anaerobic reactors its operation is difficult. Fig. 9 depicts the schematic image of anaerobic contact process [14].

2.5. Anaerobic fluidized bed reactors (AFBR)

As a result of loss of biomass during the reactor operation and due to the high quantity of solid in the effluent, the reactor efficiency gets limited [82]. Hence the reactors have been created with the additional support that adhere the biomass which leads to small HRT and high loading capacities. The Fluidized bed reactors (FBR) overcome this problem and proved high mass transfer characteristics. The schematic representation of laboratory scale FBR is shown in Fig .10. It also has the capacity to deal with the high OLRs [72]. In order to handle the surface solids in the effluent FBR are generally utilized because it occupies large biomass concentration than other reactors. In an AFBR microorganisms get adhered to the support media and the wastewater flows upward to the over support media. The transporter media incorporate plastic granules, sand particles, glass beads, mud particles, and charcoal pieces etc. The transporter

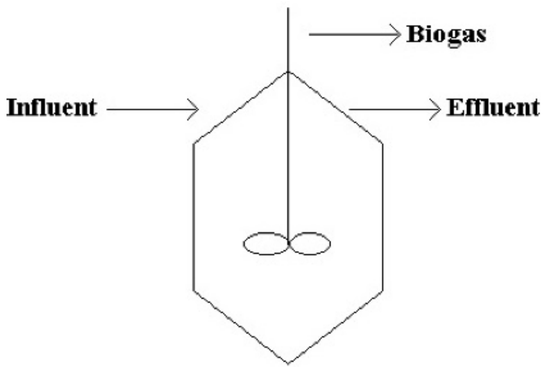

Fig. 8. Schematic representation of continuous stirred tank reactor (CSTR) [105].

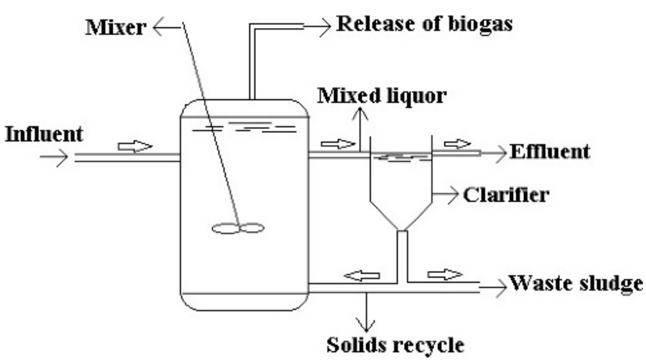

Fig. 9. Schematic representation of anaerobic contact process [14].

Table 4
Experimental conditions of CSTR in the treatment of wastewater

Type of wastewater	Volume (L)	pH	Temperature (°C)	HRT (D)	Loading rate	References
Cheese whey wastewater	6	7	55	10	0.95 Kg m^{-3} D^{-1}	[113]
Cheese whey	25	–	35	18	4.9 $gL^{-1}\cdot D^{-1}$	[114]
Cheese whey and dairy manure	26.6	–	34	10	–	[115]
Dairy cow solid waste	–	5.5	37	6	–	[116]

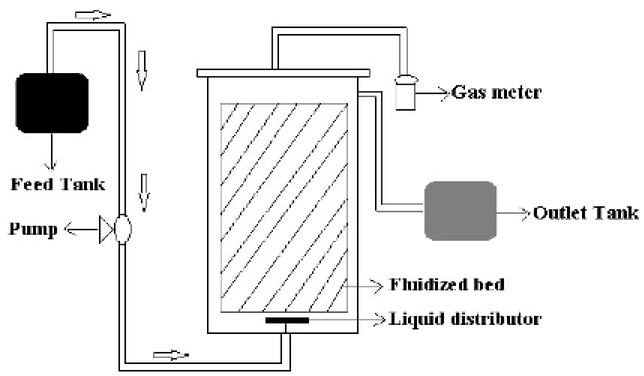

Fig. 10. Schematic representation of anaerobic fluidized bed reactor [105].

medium is continually kept in suspension by capable distribution of the fluid.

The AFBR has been effectively shown for biosolids processing and excellent in handling of high content of solids because of its improved mass and heat exchange rates and the equal distribution within the liquid phase [99]. The effectiveness of the FBR depends on certain components like high contact between liquid and fine particles carried out by microbes and has the capacity to avoid the growth of biofilm thickness. Additional care was required for the start-up of an AFBR when compared with the other types of anaerobic reactors. The benefits of AFBR are generating high biomass, high mass transfer rates, low space requirements, high flow rates, less clogging and capacity to handle high shock loads [14,100]. Moreover, it gives high surface area and good hydraulic circulation. Sowmeyan and Swaminathan [101] used inverse fluidized bed reactor for the treatment of high strength wastewater. It accomplished 84 % COD removal from 35 kg m^{-3} d^{-1}. The supporting materials employed in this reactor are perlite which provides better surface area and high biomass attachment. Finally, this system achieved excellent OLRs and COD removal rates and implies acceptable support to the deviations in OLR and HRT. The disadvantages in working with AFBR include pumping power requirement, lengthy start-up time, wasting of bio-growth etc. [100].

2.6. Anaerobic packed bed digester (APBR)

Anaerobic packed bed reactor was first introduced by Young and McCarty in the wastewater treatment system and it is related to the trickling filters that contains support material in the biofilm form [14]. Anaerobic packed bed reactor (APBR) is an efficient method for treating dairy wastewater. It also removes the waste without the process failure though the wastewater has different variations. The schematic illustration of APBR is depicted in Fig. 11 [14]. An appropriate APBR is one of the growth system which depends on the principle of arresting of microbes in the carrier media through entrapment and attachment in the support media and additionally it has the ability to hold up the biomass along with the support, increase the contact between biomass and wastewater and furthermore biogas generation and hence it has been widely used for the treatment of dairy wastewater [102]. The operational mode of APBR is up flow and down flow mode [81]. Wastewater flows from the top or bottom to make up flow and down flow arrangements. The most significant aspect in APBR design is the choice of support material like ash, volcanic stones, zeolite, wooden blocks, microorganisms, plastics, polymers, granular activated carbon and other polysaccharide materials acts as a carrier material in packed bed digester that remains in contact with the dairy effluent. A laboratory scale study was carried out using APBR by Deshannavar et al. [78] packed with polypropylene pall rings for the treatment of dairy effluent at the lower HRT of 12 h, at OLR of 5.4 kg m^{-3} D^{-1}. The COD removal was shown to be 87%. These results depicted that the APBR has high feasibility in treating the wastewater. Researchers applied this system into both laboratory and pilot scale with a material like tire rubber and zeolite. They are highly efficient in operating under the conditions like temperature (22–26°C) and HRT (3 d) [102]. APBR give high surface area for the adhesion of bacteria which leads to the prevention of wash out of microbes form the reactor. Based on the porosity, the performance efficiency of APBR varies because high porous materials found to be more efficient than non-porous materials. APBR have several advantages like simplicity of operation, high mass transfer rates and high efficiency. Non-stop operation of APBR gives inconsistent product. The anaerobic procedure has various points of interest like the generation of biogas as an energy source which comprises of 50–70% CH_4. Patil et al [80] carried out a study using two up flow anaerobic packed bed reactor (UAPBR) for the treatment of cheese whey wastewater which consists of proteins, fats, lactose and so on. The result of the work shown that based on HRT, the COD removal was achieved about 94–96%. The optimum control of temperature and pH indicated the generation of higher biogas production [80]. Deshpande et al. [103] has made an attempt to analyse the performance of UAPBR to treat whey dairy waste. They evaluated that the COD value was found to be 42–200 mg L^{-1} and concluded

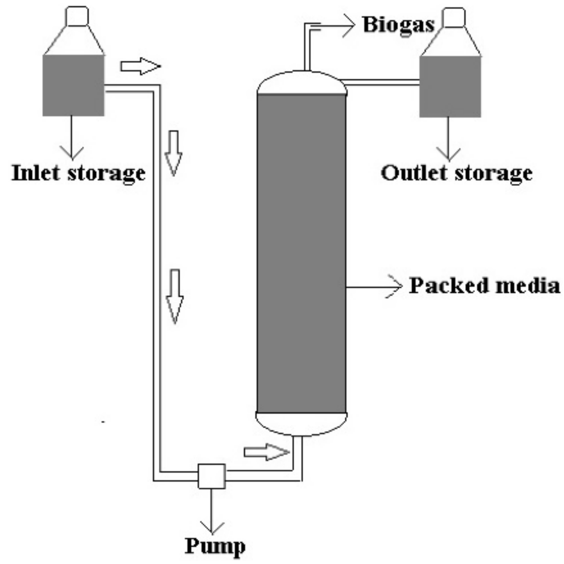

Fig. 11. Schematic representation of anaerobic packed bed reactor [14].

that the dairy wastewater is more suitable for the production of methane gas in packed bed reactor.

A study was conducted by Qazi et al. [77] for the conversion of organic constituents in the dairy effluent into biogas. The supporting media utilized in this reactor are foam cubes, bamboo rings, fire bricks, PVC rings and gravels. The percentage removal of COD, BOD and VSS were identified and then found to be 96%, 93% and 90%, respectively. Certain researchers used UAPBR which was operated under mesophilic conditions (37–45°C) for the treatment of dairy wastewater. They described that the increase of HRT, the removal percentage of COD and BOD was increased along with the biogas production [104], Hence from the outcomes, they concluded that this method is suitable for degrading the dairy wastewater. APBR system is delicate for high strong substance waste waters that make obstructing of bearer materials and decreases stability of the materials [105].

2.7. Conclusion and future trends

Dairy industry is an industry producing food products with great source of nutrients. The dairy industry produces food items such as milk, cheese, curd, whey, etc. The effluent released from the dairy industry is composed of organic, inorganic and fatty substances which are the major sources of pollutant to fresh water sources. The organic loading of the dairy industry when mixed with the fresh water sources causes eutrophication and oxygen depletion in the marine environment which lead to the aquatic life damage. The wastewater treatment is mandatory to decrease the harmful consequences of the dairy effluents. Aerobic and anaerobic techniques are the two types of biological treatment method. The biological treatment method of the dairy effluents is an extraordinary technology for treating the dairy wastewater. This effluent consists of some complicated organic and chemical components in it, the degradation also becomes difficult. In the preliminary treatment process of wastewater, only few particles such as solids, fats, oil, grease, etc,. can be excluded from the dairy wastewater. Rest of the high organic loading of the dairy effluents are treated only by the biological method. In the aerobic method, the fats and supplements could be expelled in any case without much of a stretch; high vitality necessity is an essential downside due to the supply of air circulation. Nowadays, many new techniques have been blended with the biological treatment to provide a significance removal of organic content from dairy wastewater. Distinctive blends of reverse osmosis, nanofiltration, and ultra filtration with each other or potentially with organic and additionally substance strategies are likely to end up new time of future research. Anaerobic method is most generally utilized for treating dairy waste waters, prevalently UASB and anearobic digesters. The UASB are most generally utilized also, suitable for treating dairy industry waste waters, since they can be treat extensive volumes of influents in a generally short time frame. Be that as it may, these procedures somewhat debase wastewater containing fats and supplements as dairy wastewater. Along these lines, further treatment is fundamental for anaerobically-treated dairy wastewater. The micro organisms of good removal capacity and of higher growth rate should be implemented to decrease the time consumption of dairy wastewater. The genetic engineering should be implemented in bringing out the organisms with good degradation capacity. The energy consumption should be decreased by using some of the alternative techniques and the alternative energy sources should be used in the treatment plants to support the energy consumption. The aerobic treatment is an outstanding treatment technology for removing the organic and fatty compounds in the dairy effluents. The high energy consumption and air circulation is a well known limitation of the aerobic treatment technology. The anaerobic treatment method is effective in treating the high organic content of the dairy wastewater using digesters and UASB reactors.

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