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# Sequential batch reactor for dairy wastewater treatment: Parametric optimization; kinetics and waste sludge disposal

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ABSTRACT

Dairy industry wastewater is characterized by high nitrogen load and chemical oxygen demand (COD). Present study deals with treatment of simulated dairy wastewater (SDW) in terms of COD and total Kjeldahl nitrogen (TKN) removal by aerobic sequential batch reactor (SBR). SBR was optimized for various operating parameters and four phase study was carried out by varying hydraulic retention time (HRT), filling time of SDW to the reactor, anoxic phase introduction after filling phase and react phase. Kinetic study has also been performed at various HRT. Optimum HRT ($HRT_{opt}$) of 1 d with volume exchange ratio of 0.5 was found to sufficient to treat SDW. In view of fixing the problem of disposal of wasted activated sludge (AS) during the SBR cycle, elemental and thermo-degradation analysis of sludge was performed to understand its thermal degradation characteristics and possibility to utilize wasted AS as fuel.



## Introduction

Dairy wastewater has high chemical oxygen demand (COD), biological oxygen demand (BOD) and nutrient concentration. Therefore, dairy wastewater treatment has been mandatory before its discharge into water bodies. Dairy wastewaters are generally treated using anaerobic biological methods such as up-flow anaerobic sludge blanket (UASB) reactor and anaerobic filters [1]. However, anaerobic treatment does not completely remove all organic matter and nutrients; and needs complementary post-treatment [2,3]. Also, physico-chemical methods like coagulation, electro-chemical treatment, adsorption, etc. are not able to fully degrade/remove the pollutants particularly dissolved organic compounds [4–7]. Aerobic activated sludge processes (ASP) are prone to bulking of sludge, and is very sensitive towards variation in COD and BOD loading. It also requires large area for its installation. These problems of ASP may be overcomed by using sequential batch reactor (SBR), which is a best available technique for the biological treatment of industrial wastewaters showing excellent COD/BOD removal, and is highly flexible [8]. SBR is a fill-and draw activated sludge system. In this system, a series of process phases mainly: filling of wastewater, reaction phase, settling, and decantation of treated wastewater [9] are done in a single batch reactor in sequential order, unlike to ASP. Hence, total cost is reduced by demanding lower area for installation and elimination of clarifiers and other equipments [10]. In fill phase, wastewater streamed into the SBR mixes with the biomass already present in the reactor, and this can be varied using various conditions such as static-fill (without mixing of filling wastewater with biomass), mixed-fill (mixing of filling wastewater with biomass), aerated-fill, and a combination of mixed and aerated fill. These filling conditions affect the organics and nutrient removals from the wastewater. Under the static-fill condition, influent wastewater enters into the reactor with no mixing with biomass and/or aeration. Under mixed-fill condition, influent gets mixed with biomass present in the reactor but the aeration remains off. In condition of aerated and mixed-fill, both the aeration and the stirrer are switched on and wastewater is mixed with biomass present in the SBR [11]. Also, reaction phase may be conducted under anaerobic, anoxic or aerobic conditions.

Various authors have previously reported treatment of various types of wastewaters [12–17] including dairy wastewater [18–28] by SBR. A good review on dairy wastewater treatment is available in open literature [29]. Mohseni-Bandpi and Bazari [19] used a bench-scale aerobic SBR to treat the industrial milk factory wastewater, and more than 90% COD removal efficiency was reported. The optimum dissolved oxygen in the reactor was 2 to 3 mg/l. Sirianuntapiboon et al. [20] used membrane coupled sequencing batch reactor (MSBR) and reported COD, $BOD_5$, total Kjeldahl nitrogen (TKN), and oil and grease removal efficiencies of 89.3, 83.0, 59.4 and 82.4%, respectively, when treatment was done

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**Abbreviations and symbols**

| | |
|---|---|
| BOD | biological oxygen demand (mg/l) |
| COD | chemical oxygen demand (mg/l) |
| UAFB | up flow anaerobic fixed bed |
| AS | activated sludge |
| ASP | aerobic activated sludge processes |
| SBR | sequencing batch reactor |
| MSBR | membrane coupled sequencing batch reactor |
| TKN | total Kjeldahl nitrogen (mg/l) |
| $TKN_F$ | TKN at the end of filling phase (mg/l) |
| $TKN_{eff}$ | TKN at the end of $t_R$ (mg/l) |
| OLR | organic loading rate |
| SS | suspended solids (mg/l) |
| HRT | hydraulic retention time (h) |
| $HRT_{opt}$ | optimum HRT |
| SDW | simulated dairy wastewater |
| DO | dissolved oxygen (mg/l) |
| TGA | thermo-gravimetric analyser |
| VER | volume-exchange ratio |
| $VER_{opt}$ | optimum VER |
| SRT | sludge retention time (d) |
| MLSS | mixed liquor suspended solids (mg/l) |
| SVI | sludge volume index |
| $T$ | temperature |
| $t_F$ | filling time |
| $t_{F,opt}$ | optimum $t_F$ |
| $t_R$ | reaction time |
| $t_S$ | settling time |
| $t_D$ | decanting time |
| $t_I$ | idle time |
| $t_C$ | cycle time |
| $t_{A\text{-}F}$ | anoxic phase after filling phase |
| $t_{A,opt\text{-}F}$ | optimum $t_{A\text{-}F}$ |
| $t_{A\text{-}R}$ | anoxic phase after react phase |
| $V_T$ | working volume of SBR |
| $V_F$ | fill volume of wastewater in SBR |

at high organic loading rate (OLR) of 1.34 kg $BOD_5/m^3d$. Frigon et al. [26] studied anaerobic followed by aerobic treatment sequentially at low oxygen concentration in the same digester, and reported that COD removal rate reached to 98 $\pm$ 2% in 4 d cycle time at OLR of 0.78 g COD l/d. Joseph et al. [27] reported sludge characteristic collected from six SBRs treating dairy wastewater operated at same conditions. The sludge was characterized for their morphological properties, settling, compressibility, suspended solids (SS) concentration, and reported that the sludge from each SBR was different from the others in most of the characteristics. Zinatizadeh et al. [28] studied bench scale SBR treating simulated dairy wastewater, and reported 96.5% COD removal in 18 h aeration time.

Fill time ($t_F$) of wastewater into the SBR and time of anoxic condition maintained greatly affects the organic and nutrient removal. Aerated and mixed-fill method can remove organics faster and reduces the reaction time ($t_R$). Very few studies have been reported in open literature for optimization of SBR for dairy wastewater treatment. Study on effect of filling time ($t_F$) of dairy wastewater to SBR has not been reported previously at best of our knowledge. Moreover, disposal aspect of excess sludge wasted during SBR cycle has been overlooked.

Present work was carried out to optimize the SBR for various operating parameters like hydraulic retention time (HRT), $t_F$, anoxic phase introduction after filling phase ($t_{A\text{-}F}$) and after react phase ($t_{A\text{-}R}$) for the treatment of simulated dairy wastewater (SDW) in terms of COD and nitrogen removal. For this purpose, the study was conducted in four phases by varying HRT (15–30 h), $t_F$, $t_{A\text{-}F}$ and $t_{A\text{-}R}$. At HRT values of 15, 17.14 and 24 h, kinetic study was also performed for COD removal. Slurry of the SBR has also been evaluated for sludge settleability at optimum conditions. Elemental analysis of wasted activated sludge (AS) during the SBR cycle at optimum condition has been carried out to understand the elemental distribution. A strategy for the disposal of wasted sludge has also been proposed based on thermal degradation analysis.

## Materials and methods

### *Simulated dairy wastewater (SDW)*

SDW was prepared in the laboratory by dissolving 4 g of milk powder of Amulya brand per litre of distilled water. Several authors used same method for making SDW [4–7,30–32]. SDW used in this study had similar characteristics to industrial dairy wastewater as reported by several other investigators [33,34]. The SDW was generated freshly as per requirement. Main characteristics of the prepared SDW were: COD = 3900 mg/L, total Kjeldahl nitrogen (TKN) = 113.18 mg/L, turbidity = 1744 NTU, conductivity = 220 μs/cm, chloride = 31 mg/L, and pH = 6.5. These characteristics were maintained uniform throughout the study.

### *Seed activated sludge*

AS used in the present study was collected from Haridwar sewage treatment plant, Haridwar, India. Coarse and bigger particles from the AS were first separated with the help of screen, and then, it was acclimatized in the SBR with SDW [25,35,20,36]. For this purpose, SBR was seeded with AS, and system reached to steady state within 15 days of operation. Fig. 1 shows schematic diagram of SBR used in this study.

### *Analytical measurements*

All the chemicals used in the study were of analytical reagent grade. Chloride content and TKN were measured by the standard titrimetric Volhard method and standard Kjeldahl method, respectively. Double beam UV visible spectrophotometer (HACH, DR 5000, USA) and digestion unit (DRB 200, HACH, USA) was used to measure COD. Turbidity was measured by using turbidity metre

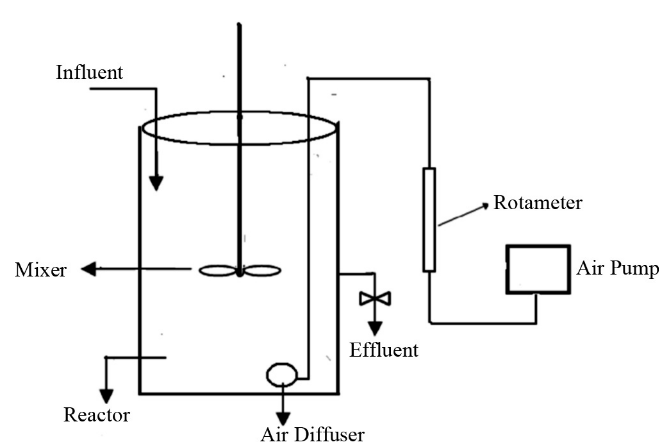


**Fig. 1.** Schematic diagram of SBR.