Effect of environmental and operational parameters on sequential batch reactor systems in dye degradation

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Abstract

1. Issues

Dye containing wastewater not effectively managed is among the major contributors to water contamination. It is considered a major threat to public health and environment. Thus, it must be handled properly before discharging into the environment. This chapter discusses the performance evaluation of sequential batch reactor (SBR) system in managing dyes. It further complied and analyzed the impact of several environmental and operational parameters on the system in dye degradation. The various variables such as cycle time, hydraulic and sludge retention times, aeration, agitation, pH, dissolved oxygen, redox potential, feeding, temperature, hydrodynamic shear force etc are described.

2. Major advances

Due to their complicated structure and synthetic root source, dyes are often regarded as one of the most difficult parts of textile wastewater to process. Environmental contamination emanating from toxic dye processing by dyeing industries continues to be a challenge. All through dye degradation, a variety of methods have been used, with various levels of efficacy, which may be attributable to differences in dye properties, discharge conditions, technical potentialities, regulatory obligations, and financial thoughtfulness. Recently, the usage of SBR in dye degradation, has continuously receive attention from scientists. It is widely preferred in dyes degradation because it is an efficient process. More so, taking advantage of the high SBR versatility, the control parameters can be changed appropriately and the decolorization potential be recovered. Owing to its operational versatility, shock load resistance, and high biomass retention, this chapter emphasized SBR application and efficiency for dye treatment in the context of environmental conservation. The chapter further stressed on the effects of environmental and operational parameters during dyes degradation. In recent decades, dye degradation has been successfully regulated by optimizing a lot of valuable environmental and operational parameters. They assist in the comprehension of bio-flocculation structure, properties, and mechanisms. These optimization strategies for environmental/operational parameters thus, paves the route for the production of fewer by-products. The application of RSM to physicochemical dye degradation processes could result in better design and optimization. Researchers focusing on dye degradation, physicochemical processes, and RSM can find the outcome of this chapter extremely beneficial. Looking at the environmental aspect and considering the high content of hazardous intermediate metabolites found in dyes, SBR system combined with other treatment technologies are more efficient for dye degradation. The content of this chapter is expected to improve readers' fundamental literacy, direct research scholars, and be integrated into upcoming laboratory experiments on SBR systems for dye wastewater treatment.

Keywords: Dyes; Degradation; Sequencing Batch Reactor; Environmental parameters; Operational parameters

1. Introduction

1.1 Environmental pollution by textile industry wastewater

Industrial operations in different mining fields, battery manufacturing, tannery, smelting, electroplating, textile, leather, petroleum processes, etc are described as the major sources of wastewater (Crini & Badot, 2008). Surface runoff, sewer infiltration and poor management of urban solid waste also generate wastewater. Organic substances such as dyes present in wastewater, pose a great environmental threat for all living organisms (Abu-Ghunmi & Jamrah, 2006). Therefore, reduction in effluent quantity and improving the quality would have major positive effects on land use and human health (Almahbashi et al., 2020; Jagaba et al., 2019; Lotito, Di Iaconi, Fratino, Mancini, & Bergna, 2011; Saeed et al., 2021).

1.2 Textile industry as a major dye source

During textile production process, the industry is considered the most resource (water and energy) intensive industry, thereby causing intense pollution (Cinar, Demiroz, Kanat, Uysal, & Yaman, 2009). It discharges large quantity of wastewater with complex pollutants composition (S. A. Ong, Ho, Wong, & Pakri, 2017). Textile wastewater resulting from a finishing, dyeing and printing industry is a complicated, highly heterogeneous and dynamic solution emanating from many polluting substances such as salts, degradable organics, enzymes, heavy metals, toxicants, sulfur, refractory organics, nutrients, heat, surfactants, basicity, suspended solids, soaps, solvents and dyes (I. Khouni, Marrot, & Ben Amar, 2012; Korenak, Ploder, Trcek, Helix-Nielsen, & Petrinic, 2018; Lotito et al., 2011).

Conferring extremely colored water, textile wastewater usually comprises 10-200 mg/L amount of dye, characterized by high temperature, alkaline pH, organic matter (COD) concentration, conductivity values and color presence (C. S. D. Rodrigues, Madeira, & Boaventura, 2009). Based on the aforementioned, it can be deduced that textile industrial wastewater could lead to serious environmental challenges because of their carcinogenic, mutagenic and toxic impacts on aquatic organisms (Lourenco, Novais, & Pinheiro, 2006). Therefore, prior to being released into the environment or any potential recycling, it is important to treat the wastewater (Assadi, Naderi, & Mehrasbi, 2018). However, it can only be reused provided conductivity and organic material are significantly decreased and color is eliminated (Zuriaga-Agusti et al., 2010). Due to a lack of water and stricter international standards, environmentally sustainable development in textile industry, is highly recommended (Klepacz-Smolka et al., 2009). This could be achieved through wastewater remediation and recycling to address the enormous environmental effect associated with the industry (Blanco, Torrades, Moron, Brouta-Agnesa, & Garcia-Montano, 2014; Jagwani, Johnson, Datta, & Lakshmi, 2018).

1.3 Environmental effects of Dye

1.3.1 Dye

Dyeing is among the many phases of the textile process where certain compounds like dye, surfactant, salt, formaldehyde and metals are being used (Koupaie, Moghaddam, & Hashemi, 2012). Dye wastewater discharged by dye processing plants, garment firms, plastic etc, is raising environmental concerns (Mehrali, Moghaddam, & Hashemi, 2010). The dyeing sector is an extreme user of water that creates high amounts of wastewater (Ogleni, Arifoglu, & Ileri, 2012). Dyes are culpable for the presence of color in textile industrial effluents, obstructing photosynthetic activity and disturbing habitats in surface and groundwater systems (Franca et al., 2015).

Dyes are often regarded as perhaps the most troublesome components of textile wastewater to be processed due to their synthetic origins and complex structure (S. A. Ong, Ho, Wong, & Raman, 2012). It is possible to classify dyes based on their solubility and chemical characteristics (Baloo et al., 2021). The common kinds can be grouped as direct, reactive, azo, acidic and basic dyes (Karimifard & Moghaddam, 2018). Phthalocyanine derivatives, triphenylmethyl, indigoid, azo anthraquinone and sulphur are the chemical dyes commonly used on an industrial level (S. A. Ong, Toorisaka, Hirata, & Hano, 2012). In the textile industry, fixation of dyes to fabrics partly befalls, thereby producing highly colored wastewater (Cinar et al., 2008; Menezes et al., 2019). Dyes wastewater usually containing refractory dyes and organic chemicals, and their metabolite derivatives are mutagenic and toxic that can hang in the air for a long duration (Bashiri, Fallah, Bonakdarpour, & Elyasi, 2018; L. L. Zhang, Sun, Guo, Wu, & Jiang, 2012).

1.3.2 Effect of dye on environment

Environmental contamination emanating from toxic dye processing by dyeing industries continues to be a challenge (S. A. Ong, Toorisaka, Hirata, & Hano, 2008; S. Sirianuntapiboon, Chairattanawan, & Jungphungsukpanich, 2006). Dye discharge in aqueous streams not only affects the clarity of natural water and its aesthetic value in terms of color, but can also hinders the penetration of sunlight, thus decreasing photosynthetic activity and oxygen bioavailability, restricts the use of water and can have a toxic impact on marine life (Azizi, Moghaddam, Maknoon, & Kowsari, 2015; Santos & Boaventura, 2015). It can also cause hemolytic anemia, hyperbilirubinemia, acute renal failure cancer and mutation in humans (Ma et al., 2011). In general, because of its resistant nature, the considerable quantity of dyes used during the dyeing phase of textile production increases the environmental hazard. To break off the health, aesthetic, and environmental issues emanating from the incessant discharge of contaminated dye wastewater, its treatment has become a complicated environmental problem. (Koupaie, Moghaddam, & Hashemi, 2013b). Therefore, developing an efficient treatment technique in terms of managing inadequate water supplies and as well the call for environmental conservation becomes paramount (Koupaie, Moghaddam, & Hashemi, 2013a).

1.3.3 Treatment of dye

Treatment system capable of COD, color and conductivity value reduction in dyes wastewater seem to be of great importance in order to recycle the final effluent (Farabegoli, Chiavola, Rolle, & Naso, 2010). But, due to dye wastewater's inhibitory and recalcitrant behavior, it is usually not appropriate to apply traditional biological wastewater treatment as most of the colored dye substances with large molecular mass are immune to biodegradation (Al-Amrani, Lim, Seng, & Ngah, 2014; S. V. Mohan, Rao, & Sarma, 2009). Strategies other than the conventional ones employed for dye containing wastewater degradation for possible reuse categorized into physicochemical, biological and combined systems have been reviewed in recent times (Khosravi, Karimi, Ebrahimi, & Fallah, 2020). According to literature, the numerous physicochemical methods used for decolorization of dyeing effluents include coagulation/flocculation, flotation, precipitation, photocatalytic degradation, ultrafiltration, pyrolyzed petrified sediment, membrane processes, electrochemical processes, ion exchange, adsorption, electrolysis, nanofiltration, reverse osmosis, irradiation and chemical/photochemical/advanced oxidation are common practices (Koupaie et al., 2013a; Lotito et al., 2011; Lucas, Peres, & Pigments, 2006; S. A. Ong, Toorisaka, et al., 2012). However, these methods are faced with one or more disadvantages of: (i) operational problems, limited versatility, economical unviability and environmental unfriendliness, (ii) generation of huge quantity of hazardous sludge, adsorbent regeneration, chemical waste generation and membrane fouling, (iii) quite inefficient, complicated, expensive, pollutants phase transfer with toxic intermediates, (iv) high operating costs and energy consumption (v) interference by other wastewater constituents (Assadi et al., 2018; Cinar et al., 2008; Hakimelahi, Moghaddam, & Hashemi, 2012)

In a review by (Chiavola, 2012), it was concluded that biological treatment methods are effective, reliable, eco-friendly, energy saving, financially appealing dye degradation techniques with minimum chemicals usage requirement. According to (S. Sirianuntapiboon & Sansak, 2008), color substances in dyestuffs contaminated water is a sort of refractory organic material, that can either be solubilized or utilized by microorganisms in traditional biological treatment systems as sources of energy and carbon. High concentration of influent color can induce partial inhibition of microorganisms that degrade color. Colorant removal mechanisms in biological systems are either based on degradation, adsorption or both (S. Sirianuntapiboon et al., 2006).

In biological treatment systems, a broad variety of microorganisms, particularly bacteria, algae, yeast and fungi, are capable of de-staining and degrading many types of dyes with bacteria and fungi as the most intensively researched (Al-Amrani et al., 2014; Cirik, Kitis, & Cinar, 2013; L. L. Zhang et al., 2012). Aerobic systems as part of the various biological processes are commonly utilized for dye degradation. Unfortunately, treatment is normally insufficient. Interestingly, the anaerobic systems can handle large amounts of organic matter, as many dyes are susceptible to reductive change in anaerobic environments. Therefore, hybrid aerobic and anerobic process is sufficient for the accomplishment of both color degradation and dye molecule disintegration (Farabegoli et al., 2010). In the hybrid environment, dye elimination is usually achieved through bond cleavage, as a result, colorless and dangerous aromatic amines are formed, along with metabolite biodegradation (Santos & Boaventura, 2015).

The typical biological wastewater treatment methods such as activated sludge process, pure culture of decolorizer, oxidation ponds, aerated lagoons and sequencing batch reactors produces less sludge (Buitron, Martinez, & Vargas, 2006; Yu et al., 2015). Recently, the usage of SBR in dye containing wastewater treatment, has continuously receive attention from scientists because it is an efficient process for wastewater treatment. SBR is widely preferred in dyes containing wastewater treatment (Ogleni et al., 2012). More so, taking advantage of the high SBR versatility, the control parameters can be changed appropriately and the decolorization potential be recovered (Moghaddam & Moghaddam, 2016).

2. Sequential Batch Reactor (SBR) system for dye degradation

2.1 Sequential Batch Reactor (SBR)

SBRs are a batch-operated form of the activated-sludge process, in which the various conditions are all met at varying periods in a single reactor, basin, or tank. The different treatment stages are performed at fixed and programmable periods, forming a cycle (Maqbool et al., 2020). The process is divided into five (5) steps: filling, reaction, settling, drawing, and idling, with aeration and clarification in between. When aeration is turned off and a drainage system is used to remove the supernatant liquor, sludge settles (A. H. Jagaba et al., 2021). The process design of the SBR system is a function of the influent load, biomass mass and settleability, reactor capacity, aeration system, and the fractions of the overall cycle allotted for the individual treatment steps (Bungay, Humphries, & Stephenson, 2007). SBRs are furnished with diffusers, inlet and outlet valves, oxygen supplying kit's and mechanical sludge out take devices to effectively regulate the system (Mahvi, 2008).

SBR as an alternative to conventional suspended growth wastewater treatment system is a sludge activation mechanism that has been tweaked to integrate both aerobic and anaerobic phases in a single unit for enhanced COD and dye degradation (Hakimelahi et al., 2012; Sathian, Rajasimman, Radha, Shanmugapriya, & Karthikeyan, 2014). It solves bulking sludge and low-density bio-sludge problems caused by clarifier large capacity (Ogleni et al., 2012). The traditional SBR is a crucial process for nitrification-denitrification, in which ammonia is initially oxidized to nitrite, followed by the oxidation of nitrite to nitrate and the formation of nitrogen gas (Santos & Boaventura, 2015). SBR has been widely adopted landfill leachate, phenolic compounds, nutrients and various dyes (Al-Amrani et al., 2014). It has a long history of usage in the treatment of textile waste, particularly for azo dyes elimination because they allow the fungal activity to be maintained over extended duration and may achieve better results in dye decolorization when compared with batch cultivation (Lourenco et al., 2006). A According to (Ogleni et al., 2012), SBRs are extremely effective in textile industrial wastewater degradation for organic matter, nutrients and dying materials (Ng, Wong, Kutty, & Jagaba, 2021).

Several kinds of SBR under diverse operational conditions have been largely examined for whole dyes bio-decolorization/mineralization in literature. These include; aerobic, sequential anaerobic–aerobic, sequential anoxic–aerobic bioreactors and sequential aerobic–anaerobic SBRs (Al-Amrani et al., 2014; Imen Khouni, Marrot, Amar, & Technology, 2012; S Venkata Mohan, Rao, & Sarma, 2007; S.-A. Ong, Toorisaka, Hirata, & Hano, 2005). Common aerobic methods utilized in textile wastewater treatment have been discovered not to be successful in degrading dyes and exceeding the biomass's adsorption capacity; this may be due to the dyes' bio-resistant nature (Singh, LeBlanc, & Bhattacharyya, 2008). In contrast to that, anaerobic SBR for treating dye degradation has proved to be further efficient than the aerobic SBRs that mostly accommodate organic chemicals and refractory dyes (L. L. Zhang et al., 2012).

2.2 Factors that affect SBR systems

Influent sample characteristics such as dissolved oxygen (DO), hydraulic retention time (HRT), carbon source, pH, redox potential (ORP), sludge retention time (SRT), feed pattern, organic loading rate, anoxic/oxic ratio, temperature, cycle duration and settleability are all variables that can impact SBR system efficiency (Rollemberg et al., 2019). In concurrent N and P removal systems, low temperature is rated a serious problem and is studied since it affects microbial activity in activated sludge negatively (Sekine, Akizuki, Kishi, & Toda, 2018). Although the SBR operation is economical, its service needs added proficiency and responsiveness. More so, SBR consistency creates issues like bulking, sludge foaming and trouble reaching the same starting conditions. It makes biological reactions gauging carried out with standard procedures more difficult. Operational difficulties such as COD fluctuations are also common during system operation (Ogleni et al., 2012). In other to curtail the effect of the aforementioned factors, several approaches have been adopted by researchers to address the weak performance of the aerobic biological elimination of dyes. These include: combining SBR with nanofiltration membrane, coupling photo-Fenton with SBR, integrating SBR with photocatalysis, coupled biological SBR-PAC adsorption systems, utilizing GAC to support biofilm attachment and use of novel bacterial consortia (Hosseini Koupaie, Alavi Moghaddam, Hashemi, & technology, 2013; Imen Khouni et al., 2012; Lim, Er, & Chemistry, 2000; C. S. Rodrigues, Madeira, & Boaventura, 2014; Suntud Sirianuntapiboon, Sadahiro, & Salee, 2007).

2.3 Merits of the SBR system

In terms of textile/dye wastewater decolorization, SBR offers the following advantages: (i) need small footprint and a single basin activity with no demand for a secondary clarifier (A. Jagaba et al., 2021), operates automatically with better process control abilities (ii) design, configuration, and process are simple and versatile (Al-Amrani et al., 2014; Cinar et al., 2008), cheap operation and installation charges (Mojiri, Ohashi, Ozaki, & Kindaichi, 2018), great bulking control and high tolerance to different shock loads (S. Y. Li, Fei, Cao, & Chi, 2019), (iii) high organic and dye removal efficiencies (S. Sirianuntapiboon et al., 2006), (iv) greater reaction rate at the onset of reaction (Yu et al., 2015), (v) less accumulation of toxic bio-degradable intermediates, (vi) volume required for continuous flow system is almost twice that required for corresponding fill-and-draw system (Abu-Ghunmi & Jamrah, 2006), (vii) concurrent organics, nitrogen, and phosphorus removal, elevated biomass retention, robustness, toxicity resistance, lower power consumption, and breaking up of SRT from HRT (Fongsatitkul, Elefsiniotis, Yamasmit, & Yamasmit, 2004; Lemus-Gomez, Martinez-Trujillo, Membrillo-Venegas, & Garcia-Rivero, 2018; Mace, Mata-Alvarez, & Research, 2002). Most of the aforementioned advantages could also be attained through microorganisms utilization (S. A. Ong, Toorisaka, et al., 2012) for dyes degradation from industrial discharge. SBR operational flexibility is convenient for dye effluents degradation, considering the fact that reaction time could be linked to the feed load with seldom organic loads. The system do allow settling time to be manipulated but also enables single pulse feeding, leading to an undesirable inventory of transient carbon substrates for filamentous bacterial growth (Albuquerque, Lopes, Serralheiro, Novais, & Pinheiro, 2005).

3. Environmental and operational parameters effects on SBR system

In recent decades, many valuable environmental and operational variables for dye degradation have been successfully implemented (Ye et al., 2009). These variables have a strong influence on the effectiveness of the SBR system, as such, there is a direct correlation among the variables and treatment efficiency. These can be determined by looking at how they affect biological nitrification, denitrification and dephosphatation, as well as, substrate storage and utilization, population and structure of microbial communities, biofilm formation, granulation and toxicity (Liao, Droppo, Leppard, & Liss, 2006). More so, they aid in the understanding floc structure, properties, and bioflocculation mechanisms. Therefore, the implications of these variables should be studied in depth for the purpose of establishing a reliable and effective biological treatment process (L. Tan, Qu, Zhou, Ma, & Li, 2010). Table 1 compiles the efficiency of different dye-treatment reactors. This is to explicitly indicate the role of several operational and environmental variables on dye degradation in an SBR system. The table further state the optimal conditions attained for each parameter during each experimental study. It was clear from literature that the majority of the treatments were aimed at removing color and COD.

3.1 Cycle time

Eq. (1) is used to describe a loop in SBR, where an entire cycle duration (t_C) is the sum of the fill, react, settle, decant, and idle times.

$$t_C = t_F + t_R + t_S + t_D + t_I \tag{1}$$

where,

t_F = fill time (h),
t_S = settle time (h),
t_R = react time (h),
t_I = idle time (h) and
t_D = decant time (h) (Thakur, Mall, & Srivastava, 2013).

The effect of the cycle duration has been seldom investigated. It can be seen that the continuous reduction in cycle duration led to an improvement in biomass composition as a result of a more plentiful organic portion (Khalil & Liu, 2021). Operating an optimized cycle time SBR system could possibly support sludge particles agglomeration with improved settleability and maintain comparable COD and color removal. Excellent phosphorus removal was observed at a short cycle length. This may be attributed to higher rate of nitrogen eliminated through the nitrite route, which renders biodegradable carbon more available. However, as the cycle length rose, the system's phosphorus percentage removal decreased due to the need for biodegradable organic carbon denitrification continued to increase in conjunction with total nitrification (Ginige, Kayaalp, Cheng, Wylie, & Kaksonen, 2013).

An aerobic SBR employed as a post treatment to anaerobically treat mixture of three different dyes has the potential to farther remove pollutants from wastewater. The SBR demonstrated the ability to handle the dye mixture at variable cycle times where the cycle duration of 12 hours was observed to be the best at producing excellent effluent while still adhering to SS and COD regulatory limits (Singh et al., 2008). In similar research for azo dye remazol brilliant violet 5R (RBV-5R) treatment, it has been revealed that reducing anaerobic cycle time did not alter the systems color removal rate. The best SBR efficacy for color and aromatic amine degradation was achieved after a total cycle period of 24 hours. The efficiency of COD removal was harmed when the total cycle length was reduced from 48 to 24 hours (Cinar et al., 2008). However, shortening cycle duration from 24h to 8 h did not affect the decolorization rate as reported by (Assadi et al., 2018).

3.2 HRT

HRT could be regarded as a measure of the mean duration whereby wastewater lived in a bioreactor system. The HRT computation for an SBR system is given by:

$$HRT = \frac{(t_C)}{V_F/V_T}\frac{1}{24} \tag{2}$$

where V_F in Eq. (2) represents the amount of wastewater filled and collected effluent for a full cycle, V_T represents the reactor's total working volume, and t_C represents the total cycle length (Thakur et al., 2013). HRT is an important parameter in biological wastewater and hydrogen production processes (Srisuwun et al., 2018). Increment in HRT offer ample time for COD and other system intermediates fractional mineralization (Assadi et al., 2018). For dyestuff wastewater treatment using only biological system as SBR, longer HRT is required (X. Xu et al., 2012).

Color removal performance of a GAC-SBR system has been reported to be high and stable at an increased HRT (S. Sirianuntapiboon & Chairattanawan, 2016). The rise in HRT primarily needed under low temperatures triggers decreased concentration of biomass, endogenous decay rate, specific growth rate and yield of biomass. Therefore, mindful attention should be given to the choice of the optimal HRT for efficient SBR application in dye wastewater treatment (S. Sirianuntapiboon & Chairattanawan, 2012). HRT can be lowered where possible by incorporating membrane modules that enhance system operating flux and permeability. With a decrease in HRT, the specific nitrate reduction rates, specific nitrite and ammonium oxidation rates, sludge volume index and specific oxygen absorption rates all inflate. Therefore, causing a reduction in microbial population through the biomass washout, continual HRT lowering could further degrade system efficiency (Lotito, Fratino, Mancini, Bergna, & Di Iaconi, 2012).

3.3 SRT

In an activated sludge process, SRT is an important design and operating variable for controlling process parameters, such as effluent water quality, nitrification, sludge volume, oxygen demand, and growth status (S. N. Xu, Wu, & Hu, 2014). It refers to how long an organism settles in a bioreactor on average. According to literature, to keep organisms alive in a batch reactor, the level of net growth must be ≥ the SRT.

SRT can indeed be calculated mathematically using the equation below:

$$SRT = \frac{V \, x \, X_{\mathrm{r}}}{Q \, x \, X_{\mathrm{e}}} \tag{3}$$

where

V = useful reactor capacity;

Q = effluent quantity per day;

X_r and X_e = influent & effluent VSS concentration (Sekine et al., 2018).

SRT obtained from Eq. (3) can be managed by activated sludge wasting regularly. The equation can be utilized to calculate the waste volume:

$$Q_w = \frac{V}{SRT} \tag{4}$$

where:

Q_w in Eq. (4) = suspended solids wasting rate, L/d;

V = working capacity of the reactor, L (Esparza-Soto, Nunez-Hernandez, & Fall, 2011).

In biological nutrient removal operations, SRT could be utilized to change the microbial population. It takes a much longer duration to achieve huge nitritation rates as SRT is raised. The nitrification start-up period would be shortened because of the comparatively short SRT. Shorter SRTs have a higher nitrite accumulating rate (NAR). Diverse floc morphology may result from using an SBR at varying SRTs. Low SRTs are associated with uneven sludge floc morphology.

Divergent SRTs are likely to have significant differences in effluent SS rates. The potential of the sludge to flocculate varies, this depends on SRT. A study treating Acid Red 14 showcases the ability of SRT versatility to eliminate color by azo dye depletion in activated granular sludge systems. SRT regulation to 15 days led to 30% decrease in color removal rate. Nonetheless, increasing SRT to >25 days regressed the impact and aided the total bioconversion of the known aromatic amine through the aerobic reaction period (Franca et al., 2015). In another related study treating highly concentrated dye in an AnSBR, the system efficiency maintained firmness for 30 days at short HRT and long SRT (Srisuwun et al., 2018).

3.4 Feeding

This is the process of loading a reactor with dye wastewater combined with biomass for microbial activity, whether by pumping or by gravity among reactors at low and high-water levels. Aerated, static, and mixed fill are all fill strategies that can be managed by a time controller. Continuous vs. pulse feeding does not alter the biomass-dominant bacteria greatly (Ciggin, Rossetti, Majone, & Orhon, 2012). It is of note that, what reactor is fed with (carbon source) and its concentration significantly matters in SBR system during dye degradation. Because of dye wastewater complexity, external carbon sources sometimes referred to as co-substrates are usually employed for the sustenance of the reactor (Sirlanuntapboon, Sadahiro, & Salee, 2007).

Adding Thai rice noodle wastewater increased dye removal efficiency by 30% (S. Sirianuntapiboon & Sansak, 2008). Discussing about co-substrate and its efficacy, it has been noted that the Reactive Black 5 removal efficiency was enhanced as influent co-substrate concentration increased (S. A. Ong, Ho, et al., 2012). Increasing OLR has been proven that it increases dye removal efficiency but deteriorates COD (Kocyigit & Ugurlu, 2015). It is a general observation that high initial dye concentrations can cause a reduction in dye percentage removal. This implies that volumetric loading rate can affect dye removal efficiency in SBR (I. Khouni et al., 2012). Dyes removal efficiency of a bioreactor system is said to decrease with increase in influent dye concentration (S. Sirianuntapiboon & Sansak, 2008).

3.5 Shock loads

An abundance of particulate organic matters might sometimes be nourished to SBRs, which could require extra HRT to process. Therefore, it becomes important to analyze a batch reactors efficiency at shock loading state when dealing with dyes since it is complicated wastewater. Sudden unplanned changes in influent concentration, also known as organic shock loading, can cause treatment efficacy to be disrupted over time. Shock loading causes stress to the bioreactor. This can be standardized by incorporating surplus common co-substrates (Khalaf, Ibrahim, Fayed, & Eloffy, 2021). The experimental recuperation time is usually longer than the theoretical recuperation time throughout shock loading. This may be because of the toxic compounds available in the wastewater having an inhibitory effect (Mizzouri & Shaaban, 2013).

Hydraulic, organic, toxic and combined loads are examples of typical shock loads. The toxic shock load occurs by the use of organic solvents to raise pollutant concentrations in a batch reactor blended well above activated sludge process's threshold level. Various COD concentrations can be applied at different time interludes to produce organic shock load. By adulterating the reactor wastewater, differences in COD concentrations can be produced. Reducing HRTs of stressed batch reactors generates hydraulic shock loads. This causes a major constraint for the reaction rate. For the combined shock load, two (2) or three (3) of the above state shocks are concurrently applied to the reactor, with varying intensity levels at given cycles, and the reactor's efficacy in wastewater treatment is then assessed (Mizzouri & Shaaban, 2013). Organic loading of 0.56 and 0.75 Kg COD/cum-day rates have exhibited less impact on the treatment of Acid black 210, as the reactor effectiveness was not restrained at the examined loading rates (S. V. Mohan et al., 2009).

3.6 Agitation

The degree of agitation is critical for creating better mixing environments, solubilizing suspended organic compounds, and enhancing mass transfer. These characteristics contribute to a higher rate of substrate consumption, which can shorten the total cycle time. Mechanical stirring, biogas and liquid recirculation can all be used to provide agitation in an SBR system. The dynamics of volatile acid production and utilization were clearly changed by increasing mass transfer resistance, enabling the device to achieve different observable steady states at a lower rate of agitation (Alami, Alasad, Ali, & Alshamsi, 2021). A research reveals that the production of biogas was insufficient to increase the turbulence required to minimize the occurrence of possible fixed zones as well as mass transfer resistance. As a result, an anaerobic SBR was produced, with agitation provided by diaphragm pump recirculation of the effluent. Authors concluded that effluent recirculation can be used as a method of agitation. The maximal recirculation velocity for an AnSBR device utilized during wastewater treatment was tested to assess the effectiveness of recirculation. When the machine was operating at lower speeds, mass transfer was found to be a constraint. Higher velocities, on the other hand, can reduce microbial activity due to excessive shearing, which can harm the flocs in the biomass and trigger granule rupture, resulting in poor solid separation (Maurina et al., 2014).

3.7 Aeration

In aerobic sludge granulation, aeration is a very important parameter (D. Xu et al., 2021). Sluggish aeration levels in SBRs might lower overall nitrite and nitrate levels, lowering the carbon demand of denitrifying bacteria and resulting in far more carbon sources being prepared for denitrification processes. The oxygen-depleted environment can enhance dye biodegradability and lessen refractory substances toxicity, allowing nitrifying and denitrifying bacteria to develop in the SND phase longer. According to the literature, a higher aeration rate helps in rapid aerobic granulation (Azizi et al., 2015). To maintain the stability of aerobic granules, it is also necessary to render adequate hydraulic sharpening power to prevent filamentous bacteria overgrowth. However, it has some drawbacks, including high costs due to energy demand, inability to remove TN, degradation of anaerobic conditions, and low phosphorus removal, among others. A traditional SBR system's aeration process can be changed, resulting in an intermittent aeration SBR, which is described as a mechanism in which anoxic and aerobic environments are formed by intermittently redoing aeration and non-aeration cycles. The key benefits of using intermittent aeration in SBRs entail improved nitrogen removal and lower operating costs.

Micro-aeration strategies tested for Direct Black 22 tetra-azo dye treatment has enhanced aromatic amine reduction and ecotoxicity. The uninterrupted micro-aeration resulted in four times greater oxygen consumption compared to the intermittent phase. However, intermittent micro-aeration attached to anaerobic digestion became the better choice with far lower oxygen intake compared to the undisturbed micro-aeration process and an extraordinary total acute ecotoxicity removal (Menezes et al., 2019). Studying the effect of aeration in Reactive yellow 15 dyes degradation at microaerophilic and anaerobic states, the removal of dye was greater than the aerobic conditions, with robust removal of dye for elevated YD concentrations. In the anoxic period, azo dye, ammonium, organic carbon concentrations were significantly reduced treating dye wastewaters in bioreactors (Sarvajith, Reddy, & Nancharaiah, 2018). In a related study using Reactive Blue 21 (RB21) dye, the aerobic phase could not significantly eliminate RB21 and greatest dye degradation happened in the anaerobic stage. Given the phthalocyanine dye's high solubility and molecular structure strength, microorganisms were unable to significantly affect RB21 molecules during the short anaerobic duration of 4h. Surprisingly, surfactant and COD degradation were significantly improved at the high aerobic phase 17h (Khosravi et al., 2020). Successful color biodegradation for mono-azo dye Reactive Red 195 (RR 195) has been stated to befall under anaerobic conditions (Farabegoli et al., 2010) .

3.8 Salinity

Salinity is regarded as one of the major elements that can affect the production and composition of EPS. Osmotic pressure usually generated by salinity may trigger the microorganisms to produce exopolysaccharides (Z. C. Wang et al., 2013). It can inhibit cell enlargement and division directly or indirectly. The development, effectiveness and efficiency of wastewater treatment systems can also be hindered. Increasing salinity in an SBR reactor substantially affects system performance negatively, leading to the collapse of the reactor ecosystem. It releases cellular materials, amounting to soluble COD increase and capable of affecting happily acclimated microorganisms to a steady salinity. The SBR system is delicate about salinity shock, and it is difficult for the main anti-salt microbes to respond well to a higher salt concentration range instantly. However, it is contradictory that some scholars claim that increasing wastewater salinity may boost SVI, while others insist that salinity increase could result to SVI reduction. High salinity is required for a batch reactor to attain a steady short-cut nitrogen elimination as the process rapidly changes to partial nitrification. However, results in stronger inhibition as it can repress NOB and AOB population.

High salinity also have powerful inhibition on the activated sludge's phosphorus degradation and nitrification capacity (Ye et al., 2009). It also contributes to soluble microbial products aggregation and decreases effluent quality. The increase effluent suspended solid concentration, disintegration of activated sludge flocs, decline of organic matter removal rate, increase of buoyancy force and inhibition of bacterial metabolism are ways by which salinity negatively affects an SBR treatment system. A study by (Wu, Guan, & Zhan, 2008) revealed that, although microbial community structure is greatly influenced by salinity, SBRs performance in terms of organic matter extraction is not affected by high salinity. Efficient methods for saline wastewater treatment have been established by the combination of fluidized bed with activated sludge process, cultivation of marine activated sludge utilizing sea mud, and incorporation of high salt-resistant bacteria. Increased aeration rate, reasonably prolonged aeration time or the inclusion of halotolerant bacteria may also increase the degradation of dye (Chen et al., 2018). 5

Hyper-salinity wastewater, as previously mentioned, commonly induced plasmolysis and/or loss of cell function, leading to detrimental consequences on biological treatment techniques. It could be described that azo dye was suitable for the production of a rare presiding species under lower-salt conditions and played a significant part in the arrangement of the microbial community. However, certain halophilic & salt-tolerant species may be enhanced during acclimatization as salinity is elevated. Decolorization of KE-3B was partly impaired under high salt environments, as the decolorization consortium was more susceptible to high salt concentrations. On the contrary, limited impact was witnessed on K-2G decolorization. More so, with the rise in NaCl concentration, microbial diversity proved to be more prevalent for both dyes (L. Tan et al., 2010). In a related study treating Direct Blue 85 (DB), NaCl exhibited an insignificant impact on the adsorption intensity (Santos & Boaventura, 2015). Treating Basic Red 46 in an SBR system, COD and color degradation rates reduced with rising nitrate ion and salt concentration in the wastewater (Assadi et al., 2018). Adding PACl to an SBR system treating Reactive Blue 19 enhanced effluent TSS and had no notable impact on effluent dyes, COD and turbidity (Mehrali et al., 2010).

3.9 pH

The pH value of BNR system responds to microorganisms' cell membrane permeability and electrical charge. pH directly impacts on microorganism growth and activity in the environment significantly. It is crucial in ensuring the prevailing position of useful bacteria in the wastewater treatment methods. As high concentration nitrate containing wastewater denitrification is controlled by pH, metal toxicity also depends pH. While studying the connection amongst pH and the degradation of biological phosphorus, the capacity of anoxic phosphate uptake was observed to be enhanced by pH rise for denitrifying polyphosphate accumulating organisms (DNPAOs) sludge. Low pH can be raised by the alkalinity generation in a treatment process (W. Li et al., 2019). To improve SBR performance, detail of the microbial population dynamics under different pH is required.

3.10 Alkalinity

Alkalinity is strongly associated with nitrogen loss. It exhibits a linear reverse interaction with concentration of the effluent nitrogen. Another benefit for alkalinity is the simplicity and ease of testing with test kits. Alkalinity < 100 mg/L does not portray adequate denitrification, while values greater than 250 mg/L indicates inadequate nitrification. Alkalinity test is usually carried out in an SBR system to observe the system operational situation and subsequently show the end of nitrification/denitrification. Nevertheless, there is currently no real-time alkalinity evaluation. Samples of wastewater had to be obtained from treatment plants and weighed by titration, resulted in several minutes time lag. Alkalinity variation amongst influent and effluent ($\Delta Alk_{inf.-eff.}$) can be employed for nitrification/denitrification lengths indicator. The influent and effluent alkalinity difference theoretical values can be computed as:

$$\Delta Alk_{theory} = 3.57([NH_4^+]_{inf.} + [NO_2^-]_{eff.} + [NO_3^-]_{eff.} - [NH_4^+]_{eff.})\ (mg/L) \quad (5)$$

since nitrate and nitrite are mostly less than influent limit, they cannot be incorporated in Eq. (5).

Alkalinity difference resulting from laboratory experiment can thus be computed as:

$$\Delta Alk_{exper.} = Alkalinity_{inf.} - Alkalinity_{eff.}\ (mg/L) \quad (6)$$

$\Delta Alk_{exper.}$ in Eq. (6) above was weighed up with ΔAlk_{theory} for ΔAlk accuracy which indicates nitrogen extraction. The existence of alkalinity consumption and formation in a single tank of an SBR system could minimize the difference in alkalinity between the influent and the effluent (B. K. Li & Irvin, 2007).

3.11 DO

DO concentration can be measured by microelectrodes to provide important details for SBR optimization. The DO concentration is said to be the most important factor in regulating SND activity SBR. It also affects granular sludge formation and aerobic granular system stability (S. A. Ong et al., 2008). Thus, altering the DO concentration could alter the aerobic zone and subsequently the bacterial community structure within the reactor. As increased levels of DO ensures total nitrification and eliminate organic carbon, a low DO state is fit for achieving high degree SND (H. Y. Wang et al., 2018). Lessened aeration levels are said to be beneficial for conserving energy and denitrification stimulation (Yan et al., 2019).

In a study where DO concentration was varied during aerobic stage, the influent solids decreased DO levels in the aerobic period from 2-0.8 mg/L and improved phosphorus removal efficiency. However, it consequentially reduced the nitrification levels proving deficiency of oxygen (Ginige et al., 2013). For the biodegradation of Acid Red 18 (AR18) dye, aerobic conditions with a 5-6 mg/L DO concentration were not adequate (Moghaddam & Moghaddam, 2016). When the effect of oxygen on the anaerobic biodegradation capacity of blended microbial culture for remazol brilliant violet 5R was investigated, increased oxygen supply had a negative effect on anaerobic color removal efficiency and azo reductase activity of anaerobic microorganisms. In the SBR dyes removal, molecular oxygen was said to have greatly decreased color removal (Cinar et al., 2009). Similarly, the increase of DO up to 3.5 mg/L did not reveal any effect on color removal by the SBR system treating Acid Orange 7 (S. A. Ong et al., 2008).

3.12 Temperature

The sustenance and growth of microorganisms alongside anaerobic degradation of organic substance are highly affected by temperature. As temperature decreases, enzymatic and chemical reactions slow down leading to total growth termination. Temperature have a significant effect on nitrogen elimination community structure in the anammox SBR with NLR, even though it has no impact on granular biomass integrity sustentation and anammox sludge grown on biofilm. Temperature decrease could transform floccular sludge microbial community structure (Q. Li et al., 2018). Great TN and SNDPR performance removal can be accomplished at less temperature (C. Li, Liu, Ma, Zheng, & Ni, 2019). However, the functions of activated sludge microbes could be negatively affected by low temperature. It has been reported that the SBR system faces numerous hurdles at temperature ≤ 10ºC. This results to the declination of denitrification and nitrification levels because of the destabilized microbial activities. Decreasing temperature can result to oversaturated DO, which hinders anoxic denitrification conduct (L. Q. Zhang et al., 2009).

3.13 ORP

A significant determinant that may affect the biodegradability of resolute micro-pollutants is the redox environment. ORP as a control parameter is essential for treatment process effectiveness optimization. According to literature, the existing redox conditions for an SBR system are: fully aerobic, anoxic/aerobic, and microaerobic (Albuquerque et al., 2005). An Orion ORP Probe are mostly used for measuring ORP. In engineering application, the accuracy of ORP for on-line monitoring is below expectation which could be due to the low pH sensitivity to nitrogen concentrations, probe fouling and difficulties in identifying breakpoints in ORP profiles comprising numerous factors (B. K. Li & Irvin, 2007). Consumption of oxidized nitrogen forms and residual DO can lead to decrease in ORP value, thereby changing the protein configuration within the system. Depending on sensor signal change, ORP reduction can be regulated either by raising/lowering the airflow or by switching the aeration on/off (Stadler et al., 2015). With and without the involvement of co-substrates and nutrients, ORP monitoring was performed in an ANSBR. The extremely active anaerobic biomass found could be due to the bioreactor low ORP values (S. A. Ong, Toorisaka, et al., 2012).

Adding variable sulfate quantity to a reactor for Remazol Brilliant R5 treatment changes the ORP values because of sulfate reduction. Larger quantity of sulphate inclusion in bioreactors with lower ORP values have a positive effect on azo dye biodegradation. Authors concluded that, the most appropriate ORP values for color removal is anything below -150 mV (Cirik et al., 2013). In a related study, it was observed that sulfate supplementation into bioreactors fed with acid dye led to sulphate decrease. However, decolorization was not improved (Albuquerque et al., 2005). In an SBR treating azo dye AO7, ORP made it easier to regulate the aerobic and anaerobic phases, as the lone control variable (Buitron et al., 2006).

3.14 C/N/P ratios

Microbial breakdown of dyes molecules largely relies on the quantity of carbon, nitrogen, and phosphorus ready for their activity. Even though bacteria cannot produce necessary enzymes required for carbon utilization with small amount of nitrogen, large amount of nitrogen can inhibit the bacterial growth (H. Y. Wang et al., 2018). The availability and nature of electron donor, conveniently denoted in terms of C/N ratio, performs a significant role in biological denitrification (Jin et al., 2013). It is a factor in the control of the denitrification efficiency, that guides in the design and configuration of the procedure to attain the aimed treatment (Y. Y. Wang, Peng, & Stephenson, 2009), and could influence microbial population dynamic of aerobic granular sludge during the continuous operation. Thus, applying appropriate proportion is important for the efficient performance of any BNR process (Khursheed et al., 2018). In an SBR treatment system, influent COD/N ration that can be calculated by Eq. (7) higher than 10 is recommended for effective nitrogen removal (C. Tan, Ma, & Qiu, 2013).

The influent C/N ratio can be calculated by the equation;

$$\text{C/N ratio} = \text{COD/TN} = c\,(\text{COD})/c(\text{TN}) \qquad (7)$$

where:

c(COD) and c(TN) stand for influent COD and TN concentrations (C. Tan et al., 2013).

Studies found that elevated COD/N ratios resulted in poor granulation as low COD/N ratios led to microorganism aggregation in reactors. Besides that, a fall in the COD/N ratio can cause an increase in the nitrification rate, rapid carbon deficit, granule destabilization and treatment downturn, major microbial community change, physical structure strength and settleability (H. Y. Wang et al., 2018). High nitrogen or low carbon due to settling of suspended load at the initial stages can lead to low C/N ratio (Khursheed et al., 2018). Consequentially, NH_4^+-N elimination performance decreases with a reduction in C/N ratio (Jin et al., 2013). In order to restrict the electron supplies for reductive half-reactions, the application of a low C/N ratio has been documented, resulting to the growth of denitrification intermediates (NO_2^-, NO and N_2O). It has certain degree of inhibition on denitrifying bacteria (Jin et al., 2013). However, in all C/N ratios tested, the utilization of surplus electron donors contributes to electron source wastefulness, increased MLSS, MLVSS and effluent COD. Decreasing C/N/P led to a consistent improvement in the COD removal efficiency in the SBR to 99.95% (Chao et al., 2020). In a related study, reduced COD/N ratios from 20-4 boosted bioactivity and maintained settling, while reducing nitrogen removal as a result of carbon deficiency (H. Y. Wang et al., 2018).

3.15 Mixed liquor suspended solids (MLSS)

MLSS is a highly complex and the most important operational parameter for SBR systems because it significantly influences effluent efficiency. It is the composition of specified quantity of suspended solids, combined with arriving wastewater. As a result, it should be checked on a regular basis. Sludge bulking occurs when the MLSS value is high, rendering the dye treatment system less efficient. In a dye containing wastewater, SBR system efficacy was improved to 75% by increasing MLSS values up to 2000 mg/L with 90 Turbidity and 75% COD removals (Ogleni et al., 2012). Batch experiments showed there was great potential in applying high MLSS for dye degradation. These oppose the study in which effluent quality significantly drops under high MLSS concentrations (Alattabi, Harris, Alkhaddar, Ortoneda-Pedrola, & Alzeyadi, 2019).

3.16 Hydrodynamic shear forces

Dye degradation in SBR system through aerobic granulation can be accomplished whenever fitting shear forces are employed. It has been judged that a specified hydrodynamic shear force value is essential for aerobic granules development, structure, stability and metabolism. To effectively calculate the shear forces, hydrodynamic shear forces must be considered because of the friction among biomass and liquid exterior (H. Y. Wang et al., 2018).

Thus, the shear force (τ) can be calculated by the following equation

$$\tau = \frac{25\,\mu\,F}{D_{\mathrm{P}}\,S_{\mathrm{R}}}\,\frac{1-\varepsilon}{\varepsilon^2} + \frac{1.75\,\rho\,F^2}{S_{\mathrm{R}}^2}\,\frac{1}{\varepsilon^2} \qquad (8)$$

where;

S_R = geometric section area (m^2),
D_p = equivalent diameter (m) of filling particles,
μ = absolute fluid viscosity (kg/m s),
ε = bed porosity (m^3empties/m^3 bed),
F = recirculation flow rate (m^3/s) and
ρ = fluid density (kg/m^3),

Eq. (8) above explains that shear forces are dependents on ε and D_p

Biomass density and hydrophobicity increases as hydrodynamic shear forces increase. Higher hydraulic shearing force which is mainly affected by DO greatly contribute to aerobic granules rapid development (Yan et al., 2019). This could be achieved if adequate oxygen is provided by restated and strong shear force to mitigate filament growth for the system to remain stable in the course of long-term operations (H. Y. Wang et al., 2018).

3.17 Electric Power

A study by (Aygun, Nas, Berktay, & Ates, 2014) reported the negative effects of power interruption as: poor TSS and COD removal efficiencies alongside poor sludge settling properties. It also concluded that the longer the interruption time, the greater recovery time required for system to attain steady-state. In a power related study, passing electric current density through a functional SBR system successfully removed nitrogen and phosphorus compounds by autotrophic (hydrogenotrophic) denitrification and coagulation processes respectively (Klodowska, Rodziewicz, & Janczukowicz, 2018).

4. Optimization of SBR operational and environmental parameters by response surface methodology (RSM)

RSM applies statistical and mathematical modeling approaches to estimate and optimize essential parameters that influence the behavior of a given response. It is an effective way to construct models, design experiments, consider the relationship between variables and deduce optimal working variables. It is also used to assess SBR performance at various operational and environmental conditions, especially in dye containing wastewater treatment (Sathian et al., 2014). It is commonly used to improve the treatment ability of synthetic dyes-contaminated wastewater. As a successful technique, RSM also has the potential to model and optimize over four efficient factors, which could lead to more useful and informative performance. Among RSM's different design approaches, such as Central Composite Design (CCD), Box-Behnken Design (BBD), Full Factorial Design and Doehlert Design (DD), CCD was perhaps the most popular. CCD joined with RSM overwhelms the constraints of several classical approaches. Most researchers have studied ≤ 4 variables and pH, RT and C0 were the most common response variables in all procedures, with %R being the most common response.

Currently, the most popular computer program for RSM are Minitab and Design Expert. In recent studies, no particular pattern has been noticed regarding the kind of dyes (Karimifard & Moghaddam, 2018). The effects of SRT, dye concentration, and HRT were investigated using AnSBR on Reactive Red 159 decolorization employing RSM via a central composite design following non-sterile and anaerobic conditions (Srisuwun et al., 2018). The CCD was chosen because of its capacity to support a range of factors and provide a definite prediction. In the study, CCD was fitted applying the second-order polynomial quadratic equation (eqn (6)) with three independent factors including HRT, dye concentration and SRT, while the decolorization was the response variable. Model expressions adoption or rejection was carried out on 95% percent confidence level probability *(P)* value. The findings were analyzed using variance analysis (ANOVA).

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i \geq j}^{k} \sum_{i=1}^{k} \beta_{ij} X_{ij} X_j \qquad (6)$$

where,

i - linear coefficient,
j - quadratic coefficient,
k - number of factors,
X_i - coded experimental levels of the variables.
Y - predicted response
β_0 - constant,
β_i - linear coefficient,
β_{ii} - interactive coefficient (regression coefficients for quadratic effects)

Table 1 SBR Dye removal efficiency

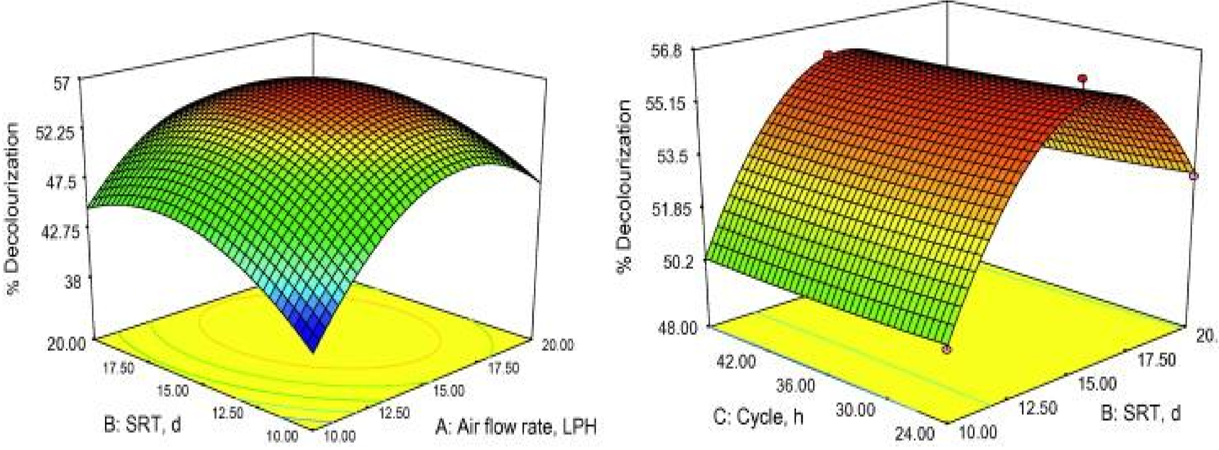
Type of dye	Dye concentration (mg/L)	Focused parameter	Operational capacity of the reactor (L)	Cycle duration (h)	HRT (d)	SRT (d)	Optimal conditions	Percentage removal (%)	Reference
Reactive Brilliant Red K-2G	500-1100	Salinity: NaCl		12			150 g/L salt, max. decolorization rate 2185.38 mg/(l.d) at 1100 mg/L dye	≈100	(L. Tan et al., 2010)
Reactive Brilliant Red KE-3B	200-800	Salinity: NaCl		12			50 g/L salt, max. decolorization rate 392.05 mg/(l.d) at 400 mg/L dye		
Acid Red 18	0-280	Feeding	5.5	24	2.75	12	35 mg/L dyes	44 dyes >85 COD	(Hakimelahi et al., 2012)
Basic Red 46	5-500	HRT, cycle time & salinity	10	8-24	1	20		65 dyes	(Assadi et al., 2018)
Reactive Black 5	10-250	Feeding	1.8	24			467 mg/L COD; 200 mg/L dyes	98.97 dyes 94 COD	(S. A. Ong, Ho, et al., 2012)
Acid Red 18 (AR18)	50-100	DO	5	6	0.375		4.0 mg/L maximum DO; OLR of 1.1-1.4 kg/m^3	38 dyes >85 COD	(Moghaddam & Moghaddam, 2016)
Reactive Blue 19	40	Salinity	7	24	1.83	10	0-30 PACl	71.7 dyes 93 COD	(Mehrali et al., 2010)
Reactive Red 159	1000-8000	HRT and SRT	2	24	4-24	7-24	6,500 mg/L of Reactive Red 159; 20d SRT; 8d HRT	97.68 dyes	(Srisuwun et al., 2018)
Mixture of MX-8B, MX-5B & MX-2R	25-100	Cycle time		6-12			Mixture of Procion Red MX-8B, Red MX-5B and Orange MX-2R. 12 Hour cycle time,	58 COD	(Singh et al., 2008)
Remazol Brilliant Violet 5R (RBV 5R)	100	Redox Potential (ORP)	6.5	12		15	Sulphate Reducing Bacteria (SRB)	83-89 dyes	(Cirik et al., 2013)
Acid Orange 7 (AO7)	50	ORP	8	24			1:40 (substrate/co-substrate)	85 dyes 90 TOC	(Buitron et al., 2006)
Acid Red 18 (AR18)	1000	Feeding	7.7	24	2.2			97 dyes 99 COD	(Koupaie et al., 2013b)
Acid Red 14 (AR14)	40	Feeding	1.5	6	0.5		20 mg Silva nanoparticles; calcium nitrate to 60 and 120 mg NO_3/L	89 dyes	(Franca, Oliveira, Pinheiro, & Lourenco, 2019)
Reactive Red 198	20-50	Feeding	10	12-24		15	Max dye removal at 20 mg/L with 16/4 anaerobic/aerobic phases	76-98 dyes 81-94 COD	(Kocyigit & Ugurlu, 2015)
Brill Blue KN-R	20-40	Feeding	5.5	24	1.83	10	20 mg/L	57 dyes 97.22 COD	(Vaigan, Moghaddam, & Hashemi, 2009)
Methyl Orange (MO)	25-500	HRT	2.5	24	4-14		8 d HRT; 1000 mg/L COD	>75 dyes >85 COD	(Yu et al., 2015)
Remazol Brilliant Violet 5R	50-100	DO and glucose	6.5	12		15	20 - 40 mL/min	38 dyes 96 COD	(Cinar et al., 2009)

Acid Orange 7 (AO7)	15-60	Feeding	3	24		15	Anoxic REACT period 16 h	99 AO7 dyes 90-92 COD	(Al-Amrani et al., 2014)
Reactive Red 195 (RR 195)	30-50	C/N/P ratio	5	12		30-50	Alternate anaerobic–aerobic conditions, 800mg/L influent COD, 50 d SRT, 24 h-cycle time, 4h aerobic phase, inhibition at > 40 mg/L influent color loadings	97 dyes	(Farabegoli et al., 2010)
Methylene Blue (MB)	4-10	Feeding	4	4	0.333			56 dyes, 93 COD	(Ma et al., 2011)
Sirius Blue K-CFN (Direct Blue 85:DB)	50-85	Salinity		24			2.5 g salt	60-69 Color, 79 TOC, 80 COD	(Santos & Boaventura, 2015)
Acid Orange 7	125-625	Feeding	2	24			625 mg/L Color 3.5 mg/L DO	98 Color 88 COD	(S. A. Ong et al., 2008)
Reactive Blue 21 (RB21)	50	Aeration	4	24	3	10	Anaerobic-aerobic phases (8 h:13 h)	98 dyes; 98.5 COD	(Khosravi et al., 2020)
Direct Red 23	40	Feeding	10	24	3-7.5		0.89 g/L	76 dyes	(Sirlanuntapboon et al., 2007)
Direct Blue 201	40-160	Feeding	10	24	7.5	28-31	3000 mg/L MLSS, HRT 7.5 d and 40 mg/L of dyes	94–99 dyes 94–97 TKN	(S. Sirianuntapiboon & Sansak, 2008)
Procion Red H-E7B	250	HRT	2	24	1-10		Best results were obtained at 1day HRT,	65 dyes 52.4 DOC	(Garcia-Montano, Torrades, Garcia-Hortal, Domenech, & Peral, 2006)
Acid Red 18 (AR18)	500	Aeration	5.5	24	2	18	Alternating anaerobic–aerobic SBR with external feeding	88-98 dyes; 55-91 COD	(Azizi et al., 2015)
Vat Yellow 1	40	Feeding	10	24	3	5-16	0.89 g/L	75.12 dyes; 70.61 COD;	(S. Sirianuntapiboon et al., 2006)
Acid Orange 7	5 g/L	Redox Potential (ORP)	1	24	1.667	15		90-99 dyes 80 COD	(Albuquerque et al., 2005)
Orange II dye	100-600	Feeding	5	24			3730 mg/L COD dosage; max. specific decolorization rate at 0.17 g/hr	89 Color	(S. A. Ong, Toorisaka, et al., 2012)
Blue Bezaktiv S-GLD 150 dye (BB 150)	3-20 g/L	Feeding	8	24		30	Volumetric dye loading rates < 15 g dye/m^{3}d	88-97 dyes; 95-98 COD	(I. Khouni et al., 2012)
Remazol Brilliant Violet 5R (RBV-5R)	100	Cycle time	6.5	6-48			24 h cycle time	92 dyes >75 COD	(Cinar et al., 2008)
Reactive yellow 15 (YD)	10-50	Aeration	3	24			Alternating anaerobic–aerobic and microaerophilic SBR conditions, 51.6 mg/L optimum YD conc. at 80 days SBR operation	89-100 dyes; 79-95 TOC; 92-100 NH_4^+-N	(Sarvajith et al., 2018)
Tetra-Azo Dye Direct Black 22		Aeration	5	24			Intermittent micro-aeration, upon 58 days, steady state circumstances for dye and COD removal were developed.	81.4 dyes	(Menezes et al., 2019)
Acid Red 14	20-60	SRT	1.5	6		15-25	15 days	90 Color 77 COD	(Franca et al., 2015)

To unveil the fitness of the selected model, the coefficient of determination (R^2) was being utilized. Fisher's F-test was adopted to confirm the statistical significance of the fitted model. Based on the consequences of the independent parameters, contours and 3D plots for the dependent factors were determined. As response variables for mathematical models, dye effluent, decolorization, and rate of decolorization were utilized with dye concentration as a favored AnSBR shift factors. The laboratory experiment was conducted with 8 days HRT, 6,500 mg/L dyes and 20 days SRT achieved 97.68, 142.62 mg/L and 264.54 mg/L/h for % decolorization, dye effluent and rate of decolorization, respectively. The results also indicate that, there was a high-grade balance between the decolorization efficiencies experimental and predicted values.

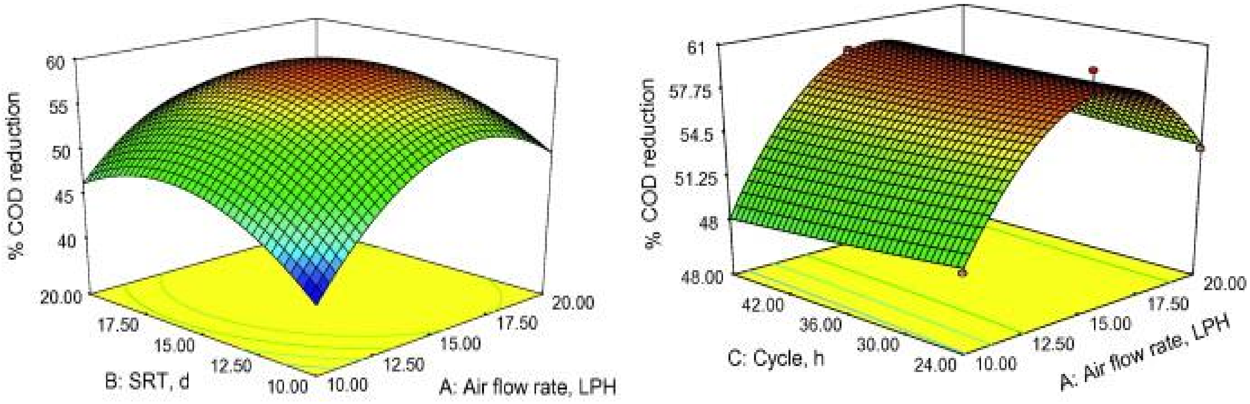
Unlike the earlier discussed scenario, all experiments were conducted in SBR mode at 5day HRT utilizing Box-Behnken design (BBD) as COD, SVI and decolorization, were evaluated for individual operational state. The impact of process variables such as cycle time, air flow rate, and SRT was examined by the authors with findings evaluated by ANOVA utilizing the quadratic regression model. For COD, SVI and decolorization, model *P* values were quite low, reaffirming the significance of the model. The predicted R^2 value agrees with the adjusted R^2 values for the three responses. SBR performance was investigated at various OLRs under optimal provisions, and the outcomes showed that OLR of 0.165 KgCOD/m^{3}d achieved COD reduction and highest decolorization of 79.4% and 71.3%, respectively. The SVI was found to be low indicating the high SBR effectiveness. To further explain the optimization studies, Fig. 1a illustrates decolorization as a function of SRT and air flow rate, confirming that decolorization often rises as the air flow rate rises. However, air flow rate > 15.9 LPH decreases decolorization. Fig. 1b demonstrated that a rise in SRT value resulted in a rise in decolorization percentage while decolorization was not affected significantly by increasing the cycle duration.

For COD reduction, similar profiles were received as depicted in Figs. 2a and 2b. As can be observed in Fig. 3a and 3b, a rise in SRT led to a reduction in the SVI value. However, at elevated SRT, the SVI value rises. This could be due to sludge disintegration at higher airflow rate. As shown in Fig. 3b, cycle duration had no negative impact on the SVI value. From this study, it can be inferred that RSM could be effectively used for dye wastewater treatment in SBR (Sathian et al., 2014). 6



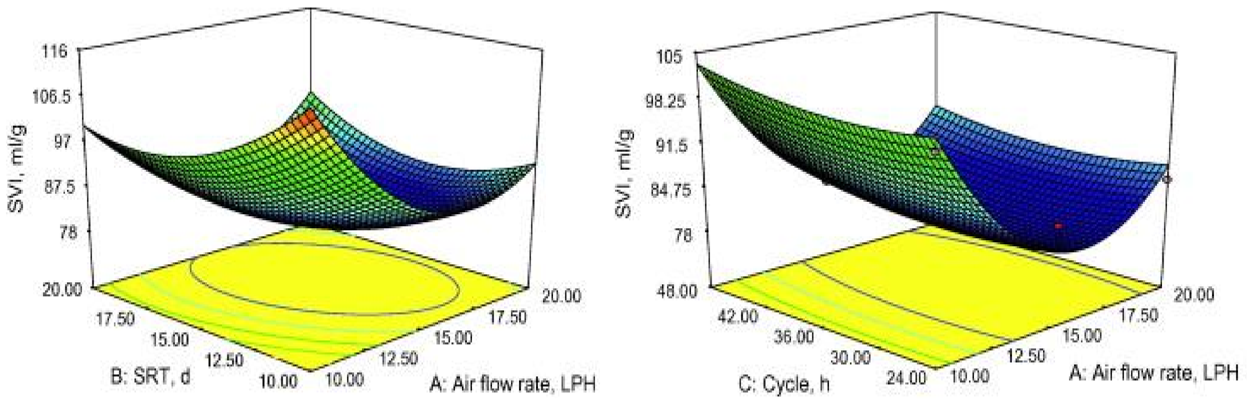
(a) (b)

Fig. 1. 3D plot of (a) SRT and air flow rate (b) cycle time and SRT effects on dye wastewater decolorization



(a) (b)

Fig. 2. 3D plot of (a) SRT and air flow rate (b) cycle time and air flow rate effects on COD reduction in dye wastewater



(a) (b)

Fig. 3. 3D plot of (a) SRT and air flow rate (b) cycle time and air flow rate effects on SVI in dye wastewater treatment

5. Conclusion

To break off the health, aesthetic, and environmental issues emanating from the incessant discharge of contaminated dye wastewater into the environment, treatment of dye contaminated wastewater has become a big environmental problem. Therefore, developing an efficient wastewater treatment technique in terms of managing limited water supplies and as well the need for environmental conservation becomes paramount. Numerous strategies have been tried for dye degradation, showing different levels of effectiveness and weaknesses as discussed in the chapter. In recent times, the usage of SBR in dye containing wastewater treatment, has continuously received attention from scholars because it is an efficient process for wastewater treatment, taking advantage of the high SBR versatility. This chapter included a thorough evaluation of current research papers, emphasizing on the usability and efficacy of the SBR system for dye treatment. The chapter went on to look at the impact of environmental and operational variables on the SBR system and arrived at the following conclusions.

- For effective use of SBR while treating dye wastewater, special attention must be given to the choice of the appropriate environmental and operational parameters. These control parameters can be appropriately changed and the decolorization potential be recovered.
- These optimization strategies for environmental/operational parameters thus, setting the stage for SBR to become a successful, long-term, and inexpensive technology with fewer by-products
- The application of RSM to physicochemical dye removal processes could result in great design and optimization. Researchers focused on dye degradation, physicochemical processes, and RSM would find this article extremely helpful.
- Due to the higher elimination of dangerous intermediate metabolites found in dyes, it is better for the environment to combine sequencing batch reactor system with other treatment technologies that are efficient for dye degradation instead of the conventional SBR process alone

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