



RESEARCH ON FABRICATION OF THE LAB - SCALE SEQUENCING BATCH REACTOR SYSTEM FOR WASTEWATER TREATMENT EXPERIMENT

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Abstract

The article discusses the fabrication of a sequencing batch reactor (SBR) with a working capacity of 5 liters and a wastewater treatment capacity of 18 liters/day. The system has continuously operated by the timers that control the automatic switching on and off of electrical equipment such as peristaltic water pumps, air blowers and solenoid valves. SBR reaction column was made of high - quality clear - PVC plastic, with 80mm inner diameter; a 15mm thick pipe wall and 1200mm total design length, easy to drill, cut and process due to its high strength and heat resistance. The electrical and mechanical parts and equipment of the SBR tank system are arranged reasonably, flexibly and easy to be removable on a V - hole iron - made support frame of 1200 mm × 800 mm × 400 mm (height × length × width). The research team has operated the newly installed SBR tank system to treat municipal wastewater taken from To Lich River, Hanoi. The removal efficiency of TSS, COD, N - NH₄⁺ and P - PO₄³⁻ reached 83.6 %, 94.3 %, 91.3 %, 48.1 %, respectively after a reaction time of 2 weeks. The successful installation of a lab - scale SBR system has contributed to improving the quality of practice for students specialized in application - oriented environmental technology and engineering.

Keywords: SBR; Batch Reactor; Installation; Wastewater Treatment

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1. Introduction

The Sequencing Batch Reactor (SBR) was named by Irvine [8] in 1971 in experimental research on wastewater treatment from the wet milling and starch production of corn refining technology in Illinois, United States. Since then, many studies from laboratory scale to full scale have been carried out to elucidate from the basic principles to the experience of applying SBR technology to the field of

wastewater treatment. In Vietnam, most municipal wastewater treatment plants have also selected SBR technology as a biological treatment facility in the wastewater treatment technology scheme [3]. Contrary to the continuous flow regime in the aerobic activated sludge system, wastewater is treated intermittently in batches in an SBR according to the principle of fill - and - draw. Each treatment batch of an SBR usually consists of 5 phases in turn: fill,

react, settle, decant and idle. Therefore, SBR technology does not need a secondary settling tank and sludge return line [8]. The microorganisms used in the SBR are usually activated sludge as those used in the aerotank. The excess amount of activated sludge will be drained in proportion to the selected sludge retention time. The significant difference of the SBR system compared to other biological treatment technologies is the control system which is a combination of sensors, timers and controllers to provide flexibility, accuracy and efficiency in the operation of the SBR system. The variation of the working time of phases, batches combined with biological processes under aerobic, anoxic, or anaerobic conditions have resulted in cycles of reactions, which can control one or more functions of organic matter treatment (COD), nitrification, denitrification and biological phosphorus removal.

However, the capacity, composition and content of pollutants in wastewater constantly change with source and time, especially in areas where intense urbanization occurs, leading to many difficulties in selecting design parameters, thereby reducing the efficiency of wastewater treatment facilities. So then, a lab - scale wastewater treatment model will set the experimental basis to determine the optimal design and operation parameters for the actual wastewater treatment system under the area's characteristics.

On the other hand, the world of information technology and control systems is also developing strongly, which has contributed to changing the control system of factors affecting the environment and operation of SBR technology towards a more modern,

accessible, more efficient for the operator [7]. Consequently, it becomes more feasible to install an automated lab - scale SBR system at a low cost. Therefore, experiments to optimize the SBR system in the laboratory are often the initial direction in - depth studies on this technology.

The purpose of this article, thus, will be to discuss the fabrication of a lab - scale SBR system for optimization research on design and operation parameters of wastewater treatment systems and meeting the practice activities of students specialized in application - oriented environmental engineering and technology, contributing to improving the quality of teaching and training. The lab - scale SBR system has a volume of 5 L, a wastewater treatment capacity of 18 liters/day, located in the laboratory of the Faculty of Environment, Hanoi University of Natural Resources and Environment.

2. Research method

2.1. Selection of materials for fabricating SBR reaction column

The research team has analyzed, evaluated and compared the two common plastic materials commonly used for lab - scale wastewater treatment models: acrylic pipe and clear - PVC plastic pipe.

Acrylic is a plastic with the scientific name of poly (methyl methacrylate) (PMMA), derived from compounds in petroleum refining. Acrylic can be transparent or colored with a variety of options. Transparent acrylic is also known as acrylic glass. In terms of shape, acrylic is usually produced in flat sheet or round tube form with various sizes, lengths and diameters to meet market demand. Both acrylic sheets and acrylic tubes are

materials used in many areas of life due to their ease of processing and low costs, such as cosmetic shelves and furniture. In particular, many researchers choose transparent acrylic material for assembling water and wastewater treatment models in the laboratory. The installed systems have high heat resistance, lightweight but solid, transparent, so monitoring the experimental processes becomes easy while ensuring aesthetics and durability [5]. With acrylic, the research team found that acrylic sheets are more manageable than acrylic tubes in fabricating processes. Due to the small wall thickness and round tube body, it is easier to crack the material when drilling and cutting than when processing on a flat sheet.

Typical PVC is in the form of pipes. Up to now, PVC pipe is still one of the most widely used plastic pipes in construction, water supply and drainage projects [6]. In addition, the PVC materials used in electrical cables and electrical equipment show a long service life and excellent

installation properties. Many toys, flooring and phone cases are made of PVC. Transparent PVC pipe with its trade name of clear - PVC has many sizes in diameter and length, is widely applied in the water supply and drainage industry due to many advantages such as flexibility, easy installation, high durability with a lifespan of more than 50 years and so - called eco - friendly. The polymers included in the plastic composition do not interact with chemically harmful substances, are not susceptible to corrosion, are resistant to the adverse effects of ultraviolet rays. Using clear - PVC pipes to make an SBR column ensures visual control over the transport of wastewater constituents inside the reactor.

The research team has designed a quantitative table to evaluate the materials between a mica pipe (Fig. 1) and a clear - PVC pipe (Fig. 2) intended for the SBR reaction column according to 5 criteria and a 5 - point scale for the most optimal level, as shown in Table 1.

Table 1. Assessment of the material selection for fabricating the SBR reaction column

No.	Criteria	Points	
		Mica pipe	Clear - PVC pipe
1	Transparency	5	4
2	Strength durability, heat resistance	3	5
3	Ability to drill, cut and process	3	5
4	Suitability as a reaction column	3	5
5	Price	5	4
Total points		19	23



Figure 1: Mica pipe



Figure 2: Clear - PVC pipe

According to the results of Table 1, the total score for clear-PVC pipe is higher, so clear - PVC pipe is selected to fabricate the SBR reaction column with a working capacity of 5L.

2.2. Calculation for designing the SBR reaction column

The research team chose a clear - PVC pipe with an inner diameter of 8 cm (80 mm), an outer diameter of 11 cm (110 mm) to design the SBR reaction column with a working capacity $V = 5L$.

The cross - section area of the reaction column:

$$F = \frac{\pi D^2}{4} = \frac{\pi 8^2}{4} = 50.272 \text{ (cm}^2\text{)}$$

The working height of the reaction column:

$$H_1 = \frac{V}{F} = \frac{5 \times 10^3}{50.272} = 99.459 \text{ (cm) } \rightarrow$$

$$\text{rounded } H_1 = 100 \text{ cm} = 1,000 \text{ mm}$$

Select the protection height: $H_2 = 20 \text{ cm} = 200 \text{ mm}$

The total length of the clear-PVC pipe needed to design the SBR reaction column:

$$H = H_1 + H_2 = 100 + 20 = 120 \text{ (cm)} \\ = 1,200 \text{ (mm)}$$

Select the distance from the center of the drilling hole to assemble the treated water collection pipe to the bottom of the tube:

$$h_1 = 40 \text{ cm}$$

Wastewater retention volume in the SBR reaction column:

$$V_1 = h_1 \times F = (40 \times 50.272)/1,000 = 2.01 \text{ (L)} \rightarrow \text{rounded } V_1 = 2L$$

The volume of treated water of each treatment batch:

$$V_2 = V - V_1 = 5 - 2 = 3 \text{ (L)}$$

2.3. Collection of equipment for the SBR system

It is imperative to operate automatically the SBR reaction column sticky to each phase and batch of time. As a result, there is a need to connect the column to an electrical and mechanical equipment system reasonably arranged on a shelf into a module that is compact, flexible, easy to disassemble and operate.

The electrical control devices of the system include:

- Peristaltic pump: Supplying wastewater from the influent chamber to the SBR reaction column in the “fill” phase;

- Air pump: Supplying air to the reaction system in the “react” phase;

- Solenoid valve: Opening the discharge valve in the “decant” phase after treatment;

- Timers: Automatically turning on and off electrical appliances;

- Electrical panels: Used for assembling timers and electrical switches for electrical appliances;

Mechanical devices include:

- Air flowmeter: Regulating the airflow supplied to the reaction column from the air pump;

- Air bubble ball: Diffusing air bubbles into the reaction system;

- Pipes of influent, treated effluent for wastewater, air supply and sludge drainage;

- Valves on the pipeline such as bottom sludge drainage valve, overflow valve, one - way valve;

- Influent wastewater and treated effluent chambers;

The SBR reaction column and electrical and mechanical equipment are installed on a support system made of V hole iron.

2.4. Preliminary experimental description with the newly installed SBR system

After completely assembling the SBR system on the shelf and electrically connecting it with timers, the authors have operated the newly installed SBR system to treat the municipal wastewater taken from To Lich River, Hanoi.

Wastewater sampling location: behind Dau bridge, on the way turning to Linh Dam new urban area which is located: 05°85'E - 23°19'N.

Sampling time: collecting 20 liters of wastewater per day for 2 weeks, from April 13, 2021.

The activated sludge for inoculation was taken from the aerotank at the wastewater treatment plant of Bao Minh Industrial Park, address KM+10, National Highway 10, Lien Minh Commune, Vu

Ban District, Nam Dinh Province, on the date April 12, 2021. Parameters of activated sludge provided by the plant: VSS = 0.3303 g/l, MLSS = 1,890 mg/l, SVI = 148.140 ml/g. The experimental operation time of the SBR system was also carried out continuously for 14 days, corresponding to the time of wastewater sampling. The number of times to take samples to analyze wastewater quality before and after treatment is 2 times, once a week, on April 16 and 23, 2021. The water quality parameters analyzed in the laboratory are SVI₃₀, TSS, BOD₅, COD, Ammonium (NH₄⁺), Nitrate (NO₃⁻), Nitrite (NO₂⁻), Phosphate (PO₄³⁻) and total phosphorus (TP). The quality of treated water is compared with the QCVN 14:2008/BTNMT - National Technical Regulation on domestic wastewater, Column A.

3. Results and discussion

3.1. Technological scheme for installation of the lab - scale SBR system

Note:

- 01. SBR reaction column
- 02. Influent wastewater tank
- 03. Effluent treated water
- 04. Peristaltic pump
- 05. Air pump
- 06. Air flowmeter
- 07. Solenoid valve
- 08. Sludge drainage valve
- 09. Timers on the electrical panel
- 10. V-hole iron shelf

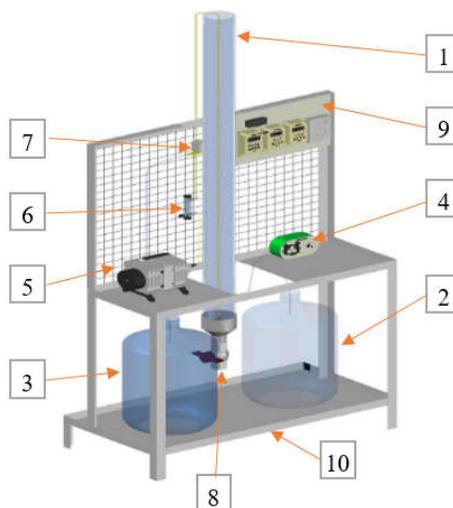


Figure 3: The lab - scale SBR system

The 5 - liter SBR reaction column is connected to the electrical equipment and water tubes, the air supply system and the sludge drainage. The two influent wastewater and treated water tanks have a capacity of 20 liters, in which the

influent wastewater one is connected to the SBR reaction column by the supply tube through a peristaltic pump. The treated effluent automatically flows into the collection tank through a solenoid valve. The air pump will supply air to

the SBR reaction column through an air bubble ball to ensure that the air bubbles generated will be evenly dispersed into the water and sludge mixture. The flow of air supplied to the reaction process is regulated by an air flowmeter. The bottom of the SBR reaction column is fitted with a cone and has a sludge drainage valve. The timers respectively control the peristaltic pump, air pump and solenoid valve to perform the opening and closing time according to the time setting of the reaction phases in a reaction batch.

All equipment, tubes of water, air and sludge, together with the SBR reaction column and electrical controller, are reasonably arranged on a supporting shelf system made of V-hole stainless iron with dimensions (height × length × width): 1200 × 800 × 400 (mm). After completing the installation, the SBR system is compact, mobile, easy to move,

disassemble and operate automatically.

3.2. Electrical connection diagram

Electrical devices connected to timers include a peristaltic pump, an air pump and a solenoid valve. All electrical appliances are compatible, suitable for single-phase alternating current, with a voltage of 220 V. The timers are installed on an electrical panel, hung on the iron rack, ensuring a safe distance from water storage tanks. The 1st timer (Timer 1) is connected to the peristaltic pump, the 2nd timer (Timer 2) is connected to the air pump and the 3rd timer (Timer 3) is connected to the solenoid valve. When it reaches the “on” time of any timer, electricity will be loaded to the corresponding device to turn on the device. Similarly, the appliance will be automatically disconnected when the “off” timer of the respective control timer is reached.

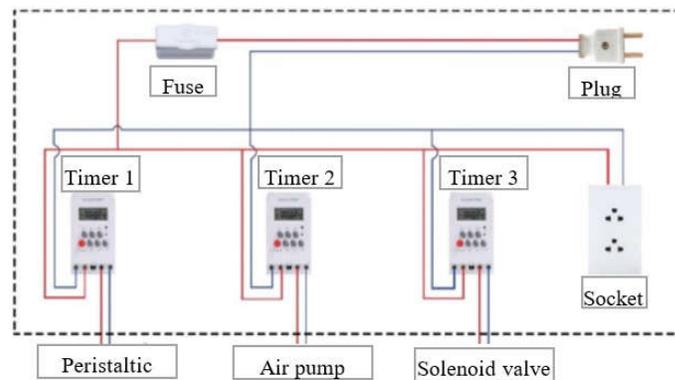


Figure 4: Electrical connection diagram

3.3. Establishment of the SBR batch cycle time

The outstanding feature of SBR technology is time - dependent operation. The time for a batch and phases can vary to ensure the efficiency of the water supply, aeration, settling and collection processes. For example, in the study of Dang Thi Hong Phuong [1], the treated wastewater is pig livestock wastewater with very high N - NH₄⁺ content in the range of 246 - 460 mg/l. Therefore, an operational cycle

time of 12 - hours for SBR was selected, of which 6 hours was the aeration time to ensure the nitrification reached 90 - 99 %. With the SBR system of Dr. Do Khac Uan [2], the water filling phase and the decant phase were carried out simultaneously. It was, after that, the anaerobic mixing phase by mechanical stirrer in the condition of no water intake, no aeration that has increased the efficiency of denitrification and COD treatment. For municipal wastewater taken from open canals such

as To Lich river, with lower COD, N and P content, the research team has set up the SBR system to operate continuously 24 hours/day at 6 cycles, resulting in 4 hours each working period. The treatment capacity of the SBR column is 3 liters/batch, equivalent to 18 liters/day. Thus, one batch of the SBR system will go through 4 sequential phases: wastewater filling, aeration, settling and decant.

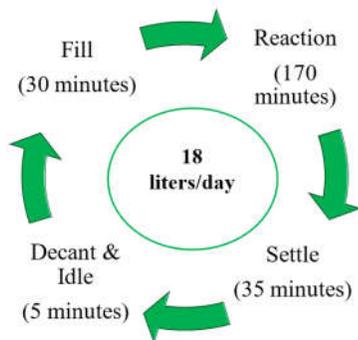


Figure 5: Phases in the SBR batch

Fill phase: The simulated wastewater or real wastewater is filled into the influent wastewater tank, capacity 20 liters. At the appointed time, timer 1 will turn on the peristaltic pump to load the wastewater from the influent tank into the SBR reaction column from the bottom up in 30 minutes. The velocity of wastewater being loaded into the SBR column is 1.4 ml/s to ensure that the activated sludge layer is not disturbed in the reaction column.

Reaction phase: After 30 minutes of wastewater filling, the peristaltic pump timer will turn off and timer 2 will instantly turn on to open the air pump and supply air to the SBR reaction column. The air blown into the reaction column is regulated at 5 l/min by an air flowmeter. The aeration process is carried out for 170 minutes. The mixed liquor of wastewater, air and activated sludge facilitates the microorganisms in the activated sludge to decompose pollutants in the wastewater.

Settling phase: After 170 minutes of aeration, the timer of the air pump will

turn off. The mixed liquor quickly turns to complete stillness. The activated sludge particles begin to settle freely from top to bottom and gradually compress into a solid sludge layer in the lower half of the SBR reaction column. The settling process is set for 35 minutes to guarantee the sludge is ultimately settled and separated from the supernatant in the upper half of the reaction column.

Decant phase: After 35 minutes of the settling phase, timer 3 will open the solenoid valve to let water flow out of the reaction column by free pressure through the collecting nozzle located in the middle of the height of the reaction column. The treated water is collected into the effluent tank with a capacity of 20 liters. The time for the treated water collection phase is 5 minutes. However, in reality, the water withdrawal from the SBR reaction column only lasts about 1 min. Therefore, the remaining time can be considered an idle phase in batches without sludge drainage or used to discharge excess sludge in batches that need to be drained.

As soon as 5 minutes of the effluent collection phase is over, timer 3 will turn off the solenoid valve. At the same time, timer 1 will turn on the peristaltic pump to start the next batch of the SBR reaction column.

Wastewater is poured into the tank once a day to ensure a stable supply for the SBR reaction column. The supernatant after treatment is used to clean and sanitize the floor of the laboratory area.

3.4. Results of experimental operation of wastewater treatment

Visual monitoring of sludge morphology combined with analysis of sludge quality parameters as shown in Table 2 represents that the sludge was well adapted to the treated wastewater environment. During the first five

days, the research team observed the appearance of filamentous sludge on the top part of the SBR column that was difficult to settle in the settling phase, causing the reduced water quality in the decant phase as the floating sludge released with the decanted water. From the 6th day onwards, the floating sludge gradually decreased, the activated sludge settled well. The supernatant after the settling phase was very clear. The SVI30,

MLSS and VSS parameters after eleven days in operation were 114 ml/g, 2.6 g/l and 0.9 g/l, respectively, showing that the density of sludge increased, the biomass of microorganisms in the sludge increased as well, but the sludge volume index rose still within the optimal range of 100-150 ml/g. The sludge content in this study is also consistent with the optimal sludge content range, which is 2-3 g/L, in the study of Dr. Do Khac Uan [2].

Table 2. Activated sludge properties

No.	Parameter	Unit	Sampling date	
			12 th April 2021	23 rd April 2021
1	SVI30	ml/g	148	114
2	MLSS	g/l	1.89	2.57
3	VSS	g/l	0.33	0.9

Table 3. Water quality before and after treatment

No.	Parameter	Unit	Results				QCVN 14:2008/ BTNMT/A
			1 st time		2 nd time		
			before	after	before	after	
1	TSS	mg/l	185	32	165	27	50
2	BOD ₅	mg/l	117.56	7.56	118.53	5.83	30
3	COD	mg/l	157.33	14.1	168	9.6	-
4	Amoni (NH ₄ ⁺)	mg/l	25.78	2.7	24	2.1	5
5	Nitrate (NO ₃ ⁻)	mg/l	0.2	1,51	0,1	1,04	30
6	Nitrite (NO ₂ ⁻)	mg/l	0.076	0.996	0.057	0	-
7	Phosphate (PO ₄ ³⁻)	mg/l	2.53	2	2.85	1.48	6
8	Total P	mg/l	3.51	2.45	4.78	2.1	-

Table 3 describes the results of the water quality analysis. The treatment efficiency of municipal wastewater in the To Lich river was reflected by TSS, COD, N - NH₄⁺, P - PO₄³⁻ parameters after ten days of operation, respectively, corresponding to 83.6 %, 94.3 %, 91.2 %, 48 %. Overall, all water quality parameters were significantly lower than column A of QCVN 14:2008/BTNMT.

The biological treatment efficiency for phosphorus in wastewater is much lower than other pollutants. It was possible because the activated sludge is not adapted to the phosphorus accumulation in the biomass. Another reason could be that the sludge retention time is long. Therefore,

phosphorus accumulated in sludge is released back into the mixed liquor during the unaerated filling phase, thus reducing phosphorus treatment efficiency.

After treatment, the remaining content of ammonium and nitrate shows that the nitrification process has not taken place completely. Studies by Phan Do Hung [4], Dang Thi Hong Phuong [1] have shown that the aeration time and wastewater supply regime greatly influence the efficiency of simultaneously COD and N treatment in the SBR system. Dang Thi Hong Phuong's research required 6 hours of aeration, accounting for 50 % of the time of a batch to carry out the nitrification process. Phan Do Hung has implemented the wastewater

supply process twice to improve the efficiency of nitrogen treatment. Therefore, improving the efficiency of N, P treatment in the newly installed SBR system will be the goal of the subsequent studies of the research team.

4. Conclusion

The research team designed and fabricated a lab - scale SBR system with a working capacity of the reaction column of 5 liters and a treatment capacity of 18 liters/day. The SBR reaction column made of Clear - PVC pipe is durable, easy to process and disassemble and ideal for applying in wastewater treatment. Furthermore, experiments with the transparent SBR column will ensure observation of phenomena occurring during operation. The SBR reaction column, together with electrical and mechanical control devices such as peristaltic pump, air pump, air - flow meter, solenoid valve, timer, water tanks, are compactly and scientifically integrated into the movable shelf system, convenient for operation and maintenance.

The SBR system can be used as an experimental model for students specialized in environmental engineering to practice wastewater treatment subjects and for scientific research to determine the design and operation parameters appropriate for characteristics of different wastewater types.

The research team conducted a trial operation of the SBR system using activated sludge to treat municipal wastewater taken from the To Lich River, Hanoi. The results show that the activated sludge taken from the wastewater treatment plant of Bao Minh Industrial Park, Nam Dinh Province, has adapted and grown well in the SBR system, maintaining the SVI30 in the optimal range of 100 - 150 ml/g resulted in good settling. TSS, COD, N-NH₄⁺, P-PO₄³⁻ treatment efficiencies reached 83.6 %, 94.3 %, 91.3 % and 48.1 %, respectively

after 2 weeks of operation.

The study of wastewater treatment on the lab - scale SBR system can bring about possible experimental results to meet the needs of upgrading the capacity to a pilot - scale practical model in the future.

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