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RESEARCH ON SBR TECHNOLOGY USING AEROBIC GRANNULAR SLUDGE TO TREAT URBAN WASTEWATER

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INTRODUCTION

1. The necessity of the thesis

Currently, in Vietnam only 10% ÷ 15% of urban wastewater is collected and treated [18]. Wastewater collection systems in urban areas of Vietnam are mostly public drainage systems. Therefore, the operative parameters of water quality parameters such as COD, BOD_5, T-P are much lower than those of the design [18]. Therefore, most wastewater treatment plants in Vietnam do not work as efficiently as designed. In Vietnam, many wastewater treatment technologies have been applied, but in regard to capacity, SBR technology accounts for the largest amount with 43.8% [18].

Aerobic granular sludge has been applied in batch reactors SBR since the 1970s and it has been extensively studied with different substances in the following years [11; 19]. Studies show that aerobic granular sludge can be widely applied to different substrates and different types of wastewater. Many studies around the world show that aerobic granular sludge can adapt to wastewater with different organic loads; according to the study of Moy et al (2002) [67], aerobic granular sludge can adapt to wastewater with organic load (OLR) from 2.5 ÷ 15 kgCOD/m^3.day, or the research by Liu et al (2007) [46] demonstrates that aerobic granular sludge can adapt well to urban wastewater with low organic load in Singapore OLR from 0.3 ÷ 0.6 kgCOD/ m^3.day. Compared with activated sludge, aerobic granular sludge has a good granular structure, high biomass retention capacity, and ability to remove more toxic compounds in wastewater [21]. Therefore, it is applied to treat domestic wastewater, wastewater from food processing plants, livestocks, industrial areas, leather processing factories, slaughter halls, breweries... [35]. It is a reliable guarantee for the studies on applying aerobic granular sludge on SBR technology to treat urban wastewater in Hanoi.

National and international research projects focus on assessing the effectiveness of organic matter removal; Nitrogen; Phosphorus; and research on optimization of operative parameters to ensure the culture of aerobic granular sludge for industrial wastewater, leachate, wastewater from food processing plants, livestocks, industrial areas, leather processing factories, slaughter halls, breweries... However, there have been no profound research projects on urban wastewater treatment in Vietnam in general and in Hanoi in particular.

Thesis: "**Research on SBR technology using aerobic granular sludge to treat urban wastewater**" is necessary to meet the practical needs of urban wastewater treatment in Vietnam today.

2. Research objectives

General objective: Research on the feasibility of culturing aerobic granular sludge and application of aerobic granular sludge on SBR technology to treat urban wastewater in Vietnamese conditions.

Detail objective: Determine the optimal process and specifications for aerobic granular sludge culture in the laboratory; Evaluate the efficiency of the pollutant removal (organic matter, ammonium nitrogen NH_4^+ -N, T-N, T-P) by SBR technology using aerobic granular sludge to treat urban wastewater in Hanoi city; Evaluate the practical applicability of aerobic granular sludge application on SBR technology to treat urban wastewater in Vietnam.

3. Subjects and scope of research

3.1. Subject of research: Aerobic granular sludge; urban wastewater with a low organic load.

3.2. Scope of research: Research on artificial wastewater in the laboratory; research on the fact of urban wastewater in Hanoi City; control parameters in aerobic granular sludge culture and operating parameters of the SBR system using aerobic granular sludge in the laboratory.

4. Method of research

The thesis uses basic researches including: 1/Methods of survey, investigation and data collection; 2/Inheriting research results; 3/Research the theoretical basis; 4/Research by model in the laboratory; 5/Methods of empirical analysis; 6/Expert method; 7/Comparison and confrontation; 8/Methods of data collection.

5. Scientific and practical meaning

5.1. Scientific meaning

- Determine parameters to be able to successfully culture aerobic granular sludge on SBR technology with laboratory-scale in Vietnamese conditions.
- Evaluate the wastewater treatment efficiency of aerobic granular sludge application on SBR technology to treat urban wastewater with low organic load.

5.2. Practical meaning

- The thesis has done an overview research on the project of culture and use of aerobic granular sludge to treat urban wastewater by using SBR technology in Vietnam and around the world: Analyze and evaluate the current status of applied wastewater treatment technologies; Research, analyze and evaluate aerobic granular sludge culture on the model of SBR technology; Research, analyze and evaluate the wastewater treatment mechanism by aerobic granular sludge on SBR technology used for urban wastewater in Hanoi. Through research on empirical models, determine the technical parameters in making aerobic granular sludge and in application to treat urban wastewater, compared with other researches in Vietnam and in the world.
- The research results of the thesis meet the current urgent need for wastewater treatment technology, and are suitable to the characteristics of urban wastewater in Vietnam.
- The research results of the thesis are a reference source to help researchers have the directions to adjust and optimize the cultivation of aerobic granular sludge in accordance with the conditions of Vietnam.

6. New characteristics of the thesis

- Successfully culture aerobic granular sludge on SBR technology with acetate OLR from 2.7 ÷ 3.0 ($kgCOD/m^3$.day) with aeration intensity q = 12 ,5 ÷ 28.5 (m^3/m^2.hour) in a laboratory in Vietnam.
- Research on successful application of aerobic granular sludge on SBR technology model to treat urban wastewater with low organic load in Hanoi City, a basis for improving SBR technology to promote efficiency of urban wastewater treatment in Vietnamese conditions. Propose a new technological line applying aerobic granular sludge to treat urban wastewater in Vietnam.

7. Structure of the thesis

Apart from the introduction, conclusion, reference and appendix, the thesis consists of 4 main chapters: Chapter 1 - Research overview; Chapter 2 - Scientific basis of applying SBR technology using aerobic granular sludge to treat urban wastewater; Chapter 3 - Experimental research; Chapter 4 - Results and discussion.

CHAPTER 1: RESEARCH OVERVIEW

1.1. Overview of urban wastewater in Vietnam

1.1.1. General problems

Vietnam is facing environmental pollution and the rapidly increasing amount of urban wastewater. According to the statistics by the Ministry of Construction (2019), the total capacity of urban wastewater in Vietnam is about 926,000 (m^3/day). Up to now, the whole country has built and operated about 70 urban wastewater treatment plants, but only 10% ÷ 15% of wastewater is treated [18].

Most urban wastewater collection network is a common sewer network and lacks synchronization, so the amount of urban wastewater is not collected thoroughly and the quality of urban wastewater is unstable.

1.1.2. Characteristics of urban wastewater collection in Vietnam

Currently, most of the drainage systems in large cities in Vietnam are public drainage systems. According to a survey report on drainage and wastewater treatment in Vietnam by JICA (2020) [18], 60 out of 71 wastewater treatment plants have input wastewater from the sewerage system with common OLR of about 0.5 ÷ 1.2 ($kgCOD/m^3$.day). There are 10 ÷ 11 wastewater treatment plants whose input is wastewater from a separate drainage system with an OLR of about 1.8 ÷ 3.5 ($kgCOD/m^3$.day).

1.1.3. Characteristics of urban wastewater in Vietnam

The majority of urban wastewater in Vietnam is collected from the common sewer system, with low organic load (COD from 90 ÷ 200 mg/l; BOD_5 from 47 ÷ 127 mg/l; BOD_5/T-N from 1.6 ÷ 2.4 mg/l). Some wastewater treatment plants such as: Buon Ma Thuot - Dak Lak; Da Lat and Lam Dong receive wastewater from separate collection systems with medium and high organic loads (with COD from 302 ÷ 564 mg/l; BOD_5 from 151 ÷ 336 mg/l; BOD_5/T-N from 2.71 ÷ 3.61 mg/l).

1.2. Overview of urban wastewater treatment technology in Vietnam

1.2.1. Popular urban wastewater treatment technology in Vietnam

There are many types of urban wastewater treatment technologies in Vietnam, currently there are 6 main technologies applied to urban wastewater treatment plants in Vietnam. If calculated by capacity, SBR technology accounts for 43.81%; CAS technology accountes for 16.7%; Ho technology accountes for 13%; OD technology accounts for 9.5%; TF technology accounts for 4.5% of capacity; A2O technology accounts for 6.9% of capacity; MBBR technology with 1.5%; AO technology with 1.3%; other technologies account for 1.5%.

1.2.2. Overview of SBR technology

SBR wastewater treatment technology is an improvement from traditional activated sludge technology. Batch reactor (SBR) is an activated sludge technology process that operates in a "charge, aeration, rest, discharge" cycle. In the world, batch reactors have been researched since the 1970s, even since 1914, the designs of wastewater treatment tanks by Arden and Lockett have operated on the principle of SBR tanks.

1.2.3. Current status of management and operation of wastewater treatment plants in Vietnam

a. Actual operating capacity and design capacity at wastewater treatment plants

Most of the urban wastewater treatment plants in Vietnam are not operating at their designed capacity. The operating capacity of the plants usually fluctuates between 50 and 70% of the designed capacity.

b. Input *wastewater quality at wastewater treatment plants*

The quality of input wastewater at wastewater treatment plants is varied in regard to different characteristics between two collection methods of the drainage system: the common drainage system and the separate drainage system.

c. Output wastewater quality at wastewater treatment plants

Most of the wastewater treatment plants come up to the current standards and regulations of Vietnam. Standard 14:2008/BTNMT: National technical regulation on domestic wastewater. However, the removal of T-N and T-P is still limited [18].

1.3. Overview of aerobic granular sludge

1.3.1. General introduction of aerobic granular sludge

Aerobic granular sludge can be defined as the microbial biomass that utilizes the nutrients in the wastewater. Granular microbial biomass is described as a dense and compact collection of microorganisms in a spherical shape. The concept of aerobic granular sludge has been developed in recent years. Aerobic granular sludge is the self-fixing process of microorganisms into a spherical mass.

1.3.2. Characteristics and properties of aerobic granular sludge

The geometry of aerobic granular sludge is spherical. The average diameter of aerobic granules varies between 0.2 ÷ 5 (mm). The specific gravity of aerobic granules is usually about 1.004 ÷ 1.065. The settling velocity of aerobic granular sludge is closely related to the particle size and structure, the settling velocity fluctuates 30 ÷ 70 (m/h), the settling velocity of aerobic granular sludge is at least three times as high as that of conventional activated sludge [52; 53]. The microbial population in aerobic granular sludge is more diverse than in conventional activated sludge [52; 53].

1.4. Relevant research

1.4.1. National research

Currently, in Viet Nam there are also a number of projects focusing on studying aerobic granular sludge with industrial wastewater such as :studying the mechanism of granular sludge formation, studying the influence of aeration flow on the granule formation process, or studying the wastewater treatment efficiency of aerobic granular sludge for industrial wastewater.

1.4.2. International research

In the world, researches on aerobic granular sludge in SBR batch reactors have been conducted since the 1970s with different substrates. These researches mainly study the mechanism of granular sludge formation such as: research on hydrodynamics and aeration intensity, gas distribution time, aeration flow.

1.4.3. Remaining issues and research directions of the thesis

a. Outstanding issues

Urban wastewater has low COD (COD from 90 to 200 mg/l) because it receives wastewater from the common sewer system. Some wastewater treatment plants receive wastewater from a separate sewer system whose input wastewater is solid one with COD from 300 ÷ 564 (mg/l) [18]. The urban wastewater treatment technology widely applied in Vietnam is SBR technology, which accounts for about 43.81% of design capacity [18]. There is a lack of researches on culturing and applying aerobic granular sludge, especially projects on raising aerobic granular sludge used to treat urban wastewater in Vietnam in Vietnamese conditions. Urban wastewater in Vietnam is dilute wastewater with the common OLR of about 0.5 ÷ 1.2 kgCOD/m^3.day. Some wastewater treatment plants have input wastewater collected from a separate sewer system. It is solid with an OLR of about 1.8 ÷ 3.5 kgCOD/m^3.day.

b. Research direction of the thesis

- Research on culturing aerobic granules at low organic load OLR less than 2.0 kgCOD/m3 (from 1.0 ÷ 1.2 kgCOD/m^3) in the laboratory in Vietnam to evaluate the ability to form aerobic granular sludge.
- Research on culturing aerobic granules at high OLR organic loads ,greater than 2.5 kgCOD/m3 (from 2.7 ÷ 3.0 kgCOD/m^3) in a laboratory in Vietnam and evaluating factors affecting aerobic granular sludge culture.
- Research on the application of aerobic granular sludge on SBR technology to treat urban wastewater in Hanoi with low organic load, OLR ranging from 0.95 ÷ 1.35

(kgCOD/m^3.day) to evaluate the effectiveness of aerobic granular sludge on SBR technology model in urban wastewater treatment in Vietnam.

- Proposing appropriate technological solutions to apply aerobic granular sludge on SBR technology to treat urban wastewater in Vietnam, enriching the source of theorical foundations in the field of wastewater treatment in the world and in Vietnam, then it can be expanded and applied practically in accordance with Vietnam's conditions.

CHAPTER 2: SCIENTIFIC BASIS OF APPLYING SBR TECHNOLOGY USING AEROBIC GRANULAR SLUDGE TO TREAT URBAN WASTEWATER

2.1. SBR technology

In the world, sequencing batch reactors have been researched since the 1970s. Sequencing batch reactor (SBR) is an activated sludge technology process that operates in a "charge, aeration, rest, discharge" cycle.

2.1.1. Urban wastewater treatment

The application of SBR technology in urban wastewater treatment has been proven through many research projects such as: Research by Bernardes and Klapwijk [21] aimed at evaluating and investigating the effectiveness of SBR technology for removing nitrogen, carbon, and phosphorus from urban wastewater in the Bennekom WWTP in the Netherlands with a capacity of 22000 (m^3/day); or research project by Umble and Ketchum [92], doing experiments with SBR technology in urban wastewater treatment. Basing on the ability of SBR technology to treat wastewater flexibly in removing organic matter, suspended solids, and nitrification; The project by Beccari et al [20] studied COD removal by acidogenic fermentation from organic wastes in municipal waste; The research project by De Sousa and Foresti [29], the one carried out on an experimental model of a UASB tank with a capacity of 4 (liters) and two identical cylindrical SBR models with a capacity of 3.6 (liters); The project by Steinmetz [77], demonstrated the effectiveness of SBR technology in 2 urban wastewater treatment plants with a capacity of 15000 (m^3/day) and 25000 (m^3/day).

2.1.2. Treating wastewater from sludge in the wastewater treatment plant

In wastewater treatment plants, wastewater from sludge can contain up to 25% nitrogen in the material stream. In the scientific report by Vandaele - Arnold et al [93], they made a comparison of the operation between SBR system and SBBR system (batch treatment tank with filter). As a result, over 90% nitrogen is removed in both wastewater treatment systems. With the above demonstrations, it can be affirmed that SBR technology is effective to treat wastewater .

2.1.3. COD removal process in SBR tank

The COD removal process in the SBR tank includes 3 Phases:

- Phase 1: Oxidation of organic substances, the rate of oxidation is equal to the rate of oxygen consumption.
- Phase 2: Synthetic cell building phase.
- Phase 3: Self-oxidation of cellular material (autolysis).

2.1.4. Nitrogen removal process in the SBR tank

a. Nitrification process

This process takes place in the aeration phase of the SBR tank with 2 following consecutive reactions:

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2 + 2H_2O + H^+ + \text{new cells} \quad (2.4)$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^- + \text{new cells} \quad (2.5)$$

b. Denitrification

During this period, 4 consecutive levels reduce respectively the valencies of nitrogen from +5 to +3, +2, +1. The overall equation is as follows:

$$NO_3^- \Rightarrow NO_2^+ \Rightarrow NO \Rightarrow NO_2 \Rightarrow N_2 \quad (2.7)$$

2.1.5. Phosphorus removal process in the SBR tank

Phosphorus is consumed by bacterial activity in the SBR reactor. Under the proper control and operation, the bacteria will effectively deal with the phosphorus in wastewater by cell immobilization.

2.2. Aerobic granular sludge

2.2.1. Factors affecting the formation and development of aerobic granular sludge

The formation and development of aerobic granular sludge depends on many factors, the main factors include: composition of the substrate; organic loads in wastewater; aeration intensity; microbial selection time; hydraulic retention time; anoxic process; technological conditions; environmental conditions.

2.2.2. Advantages of aerobic granular sludge compared to conventional activated sludge

The outstanding advantages of aerobic granular sludge over conventional activated sludge are presented in Table 2.1.

Table 2.1. Properties of aerobic granular sludge and conventional activated sludge [13; 35]

No	Properties	Aerobic granular sludge	Activated sludge
1	Settling ability	30 ÷ 70(m/h)	8 ÷ 10(m/h)
2	Biomass concentration	> 10 g/l	< 5 g/l
3	SVI_{30} index	< 50(ml/g)	60 ÷ 200(ml/g)
4	Microbial composition	Diverse, including aerobic, anaerobic, facultative bacteria	Aerobic bacteria mostly
5	Load shock resistance	high	Poor
6	Organic load	High organic load (2 ÷ 15 kgCOD/m³.day)	Low organic load (< 2,5 kgCOD/m³.day)
7	Density of mud particles	1,004 ÷ 1,065	
8	Size	0,2 ÷ 5(mm)	3 ÷ 150(µm)
9	Mud age	About 12÷ 15 days	About 6 ÷ 7 days

2.2.3. Scientific basis for treating substrates of aerobic granular sludge

To make it easier to imagine, the granular sludge structure is roughly divided into 3 layers based on the percentage of predominant microbial species.

- *The first layer,* the outermost layer of the granule sludge, includes plenty of active heterotrophic bacteria, so the COD removal process mainly occurs at the surface. Microorganisms absorb nutrients and oxygen in wastewater and release CO_2 and water.
- *The second layer,* under the outermost layer of the granular sludge, contains many highly active nitrifying bacteria, so nitrogen removal mainly occurs in this layer.
- *The third layer,* which is the innermost layer of the granular sludge, includes many highly active anaerobic bacteria, and phosphorus accumulation. The process of removing phosphorus and nitrogen, and sulfur mainly occur in this layer.

2.2.4. The ability of aerobic granular sludge to remove pollutants in wastewater

Aerobic granular sludge can be used for removing organic compounds, nutrients (nitrogen, phosphorus), heavy metals and toxic substances. Studies related to this matter have shown many advantages of aerobic granular sludge such as: capability to treat organic , N, P well; stable metabolic rate; good restoration and load shock resistance, long biomass storage time [101].

2.2.5. Kinetics of aerobic granular sludge formation

The kinetics of aerobic granular sludge formation and growth is described by equation of degree 1 [97].

$$D - D_0 = (D_e - D_0)[\ 1 - e^{-\mu(t-t_0)}]\ [97] \qquad (2.19)$$

In which: + D_0 - is the size of microbial aggregate at time t0

+ t_0 – is the stage when microorganisms begin to adapt

+ D - is the size of microbial aggregate at time t

+ D_e – is size of microbial aggregate at equilibrium

+ μ - is the specific growth rate of aggregate by size

2.2.6. Some projects applying aerobic granular sludge for wastewater treatment in the world

In recent years, the use of aerobic granular sludge for wastewater treatment tends to increase at different levels in the world such as: Opfikon Kloten wastewater treatment plant - Switzerland, capacity 26000 (m^3/day); Wemmershoek wastewater treatment plant - South Africa, capacity 5000 (m^3/day); Highworth wastewater treatment plant - United Kingdom, capacity 1444 (m^3/day); Clonakilty–Ireland wastewater treatment plant, capacity 5000 (m^3/day); Ringsend wastewater treatment plant - Ireland, capacity 600.000 (m^3/day); Kingaroy wastewater treatment plant - Australia, capacity 10.800 (m^3/day); Longford wastewater treatment plant - Australia, capacity 2.838 (m^3/day). Sappi Lanaken wastewater treatment plant - Belgium, capacity 14.400 (m^3/day). Araguaína wastewater treatment plant, Tocantis, Brazil, with a capacity of 52.704 (m^3/day) [37].

CHAPTER 3: EXPERIMENTAL RESEARCH

3.1. Contents of experimental research of the thesis

- **Experiment 1:** Evaluating the possibility of aerobic granular sludge formation in SBR tanks with artificial wastewater with the low organic load OLR in the range from 1.0 ÷ 1.2 (kgCOD/m^3.day) at model A.
- **Experiment 2:** Evaluating the possibility of aerobic granular sludge formation in the SBR tank with artificial wastewater with high input organic load OLR from 2.7 ÷ 3.0 (kgCOD/m^3.day) and evaluating the ability to remove COD and NH4+ -N at model B.
- **Experiment 3:** Evaluating the capability to treat wastewater of aerobic granular sludge in the SBR tank in model B for real urban wastewater with low organic load of 0.95 ÷ 1.35 (kgCOD/m^3.day) taken at the input of Kim Lien wastewater treatment plant - Hanoi.

3.2. Calculating and building experimental model

3.2.1. Calculating experimental model

Based on the experimental objectives and the calculation process, 02 experimental models were set up with the following parameters: 2 identical SBR tank models made of transparent Acrylic plastic with the pipe diameter of 0.110 (m), the height dimension 1 (m) high, the volume of discharge water in 1 cycle of each tank is 2.5 (liters), these 02 models are named A and B respectively. Both two SBR tanks operate at the same time (?) with 6 cycles a day, the period of time for 1 cycle is 4 hours, each cycle includes 4 phases: Feeding phase 1 ÷ 2 minutes, Aerobic reaction phase 180 minutes, Settling phase 20 ÷ 30 minutes, Effluent withdrawal phase 10 ÷ 15 minutes.

3.2.2. Building a model of SBR tank in the laboratory

Experimental model SBR is located in the laboratory of Hanoi National University of Civil Engineering. SBR technology model consists of 3 main parts: reactor tank, air supply part, controller (Figure 3.3). Model A is used for artificial wastewater with low organic load OLR in the range of 1.0 ÷ 1.2 (kgCOD/m^3.day). Model B is used for artificial wastewater with high organic load in the range from 2.7 ÷ 3.0 (kgCOD/m^3.day).

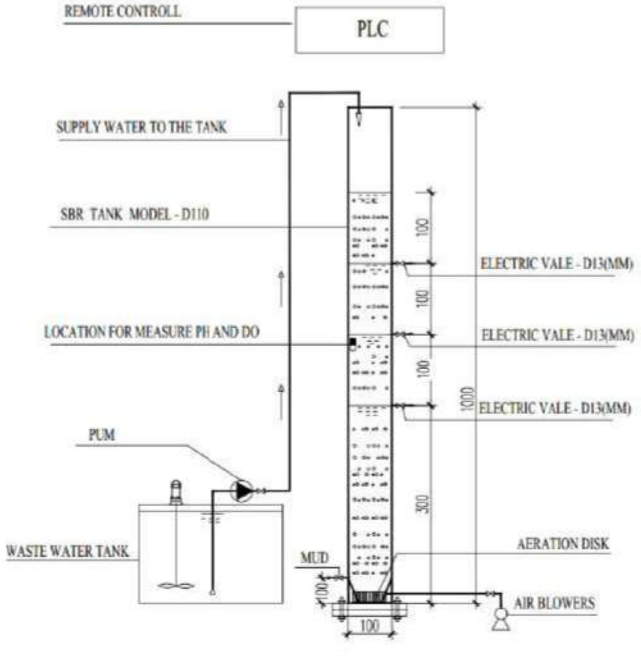


Figure 3. 3. Technological diagram of SBR tank model in the laboratory.

3.3. Research on aerobic granular sludge generation on the SBR model in the laboratory

3.3.1. Preparation of artificial wastewater and cultured activated sludge

a. Chemical preparation

The wastewater used for the experiment is synthetic artificial wastewater with the main substrate, Acetate: purity 99%, originating in China, to maintain the COD value at the rate of 1 (g) acetate 1,066 (g)COD and is added micronutrients such as: ammonium, phosphorus, some micronutrients for culturing aerobic granular sludge.

Model A

Model A uses wastewater with low organic load, simulating the characteristics of urban wastewater in Vietnam. Using synthetic wastewater with a substrate composition of sodium acetate, maintaining the input COD in the range of 350 ÷ 400 (mg/l), corresponding to the OLR organic load of 1.0 ÷ 1.2 (kgCOD/m^3.day) and adding nutrients like 45 ÷ 50 (mg/l) ammonium , 10 (mg/l) phosphorus , and micronutrients for aerobic granular sludge culture.

Model B

Model B uses wastewater with high organic load. Using synthetic wastewater with a substrate composition of sodium acetate, maintaining the input COD in the range of 900 ÷ 1000 (mg/l), corresponding to the OLR organic load of 2.7 ÷ 3.0 (kgCOD/m^3.day) and adding 45 ÷ 50 (mg/l) ammonium , 10 (mg/l) phosphorus , and micronutrients for aerobic granular sludge culture.

b. Mixing artificial wastewater

Artificial wastewater is made by dissolving the determined volume of chemicals in dechlorinated tap water. Tap water used to mix chemicals is analyzed for chloramine content below 0.1 (mg/l) to ensure that it does not affect the microflora in the reaction tank.

c. Preparation of cultured mud

The cultured sludge is the activated sludge collected at the reaction tank of Yen So urban wastewater treatment plant - Hanoi with the following properties: MLSS from 900 ÷ 1020 (mg/l), MLVSS/MLSS 79.14%, SVI 227÷ 245 (ml/gSS). The sludge entered into the SBR model at a ratio of 2.5/5 of the volume of water in the reactor.

3.3.2. Selection and control of operating parameters

The operating time designed for one cycle of the SBR system is 4 hours, 6 operating cycles a day. In 1 operating cycle of the SBR model, it is divided into 4 phases as follows: Feeding phase is 81 seconds, Aerobic reaction phase is 3 hours, Settling phase is 20 ÷ 30 minutes, Effluent withdrawal phase is 10 ÷ 15 minutes.

3.3.3. Experimental order

a. Install and start the model

The model is installed in the laboratory of Hanoi University of Civil Engineering. After assembling the model, it will be tested with clean water to check equipment such as valves, pumps, air blowers, connections...

b. Monitor and operate the model

The model is observed daily during operation. Conduct daily inspection of equipment, valves, and periodically take samples as planned. Clean the drain valve and pump chamber regularly to ensure stable operation, no mud overflow.

3.3.4. Methods of sampling, analyzing samples and processing data

a. Method of analyzing laboratory samples

Sampling and analysis were carried out in the laboratory of Hanoi National University of Civil Engineering. The following parameters will be analyzed during the research process: COD, NH_4^+ , T-N, T-P, pH, DO, TS, VS. Methods of analyzing parameters are performed suitably to Vietnamese Standards (TCVN).

b. Method of determining parameters MLSS, MLVSS, SVI

Methods of determining parameters MLSS, MLVSS, SVI are carried out suitably to Vietnamese standards.

c. Method of determining the microbial composition

Determination of the number of microorganisms in aerobic and activated sludge samples was conducted at the Institute of Microbiology and Biotechnology - Hanoi National University.

d. Method of building a mathematical model to determine the kinetic equation of the aerobic granular sludge formation process

The equation describing the kinetic parameters of aerobic granular sludge formation over time with organic load OLR 2.7 ÷ 3.0 $kgCOD/m^3$.day. models upon the kinematic equation:

$$D = 4{,}306(1 - e^{-0{,}03665t}) \quad (3.11)$$

3.4. Research on SBR technology using aerobic granular sludge for urban wastewater treatment in Hanoi in the laboratory

3.4.1. Preparation of experimental wastewater and granular sludge

a. Wastewater

Urban wastewater used for the experiment was taken from Kim Lien WWTP-Dong Tac street, Kim Lien, Dong Da, Hanoi. The characteristics and composition of experimental wastewater are as follows: COD concentration from 163 ÷ 212 (mg/l); NH_4^+ - N from 14 ÷ 70 (mgN/l); T-N from 31 ÷ 43 (mgN/l); T-P from 1.5 ÷ 2.16 (mgP/l).

b. Aerobic granular sludge for experiment

Research used 2.5 (liter) solution of aerobic granular sludge with the size 3 ÷ 5(mm), sludge concentration of MLSS 8 (g/l), MLVSS 7.8 (g/l). The sludge entered into the SBR model at a ratio of 2.5/5 of the volume of water in the reactor.

3.4.2. Selection and control of operating parameters

Similar to Section 3.3.2.

3.4.3. Experimental order

Similar to Section 3.3.3.

3.4.4. Analytical Methods

The following parameters will be analyzed during the research process: COD, NH_4^+ - N, T-N, T-P, pH, DO, TS, VS. Parameter analysis methods are performed suitably to Vietnamese Standards (TCVN).

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Aerobic granular sludge formation in the laboratory

4.1.1. Formation process of Aerobic granular sludge in model A

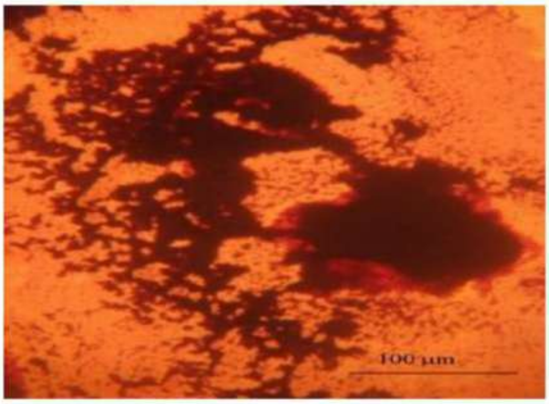
After 4 months of operating aerobic granular sludge culture in the laboratory with artificial wastewater with low organic load OLR 1.0 ÷ 1.2 ($kgCOD/m^3$.day), no sign of the granular sludge formation was recorded in model A.

4.1.2. Qúa trình hình thành bùn hạt hiếu khí tại mô hình B

4.1.2. Formation process of Aerobic granular sludge in model B

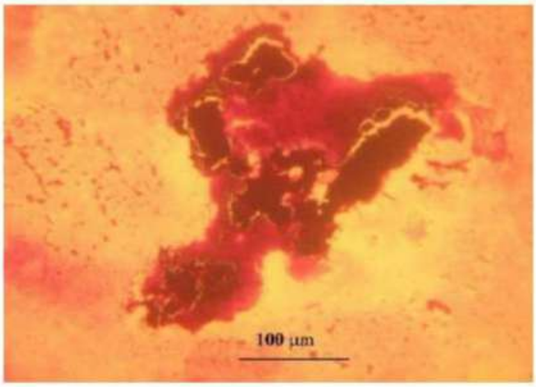
The period of time for aerobic granular sludge to form is over 4 ÷ 6 weeks. This process takes place gradually, but can be divided into 5 main stages as follows:

Stage 1 (after 7 days)



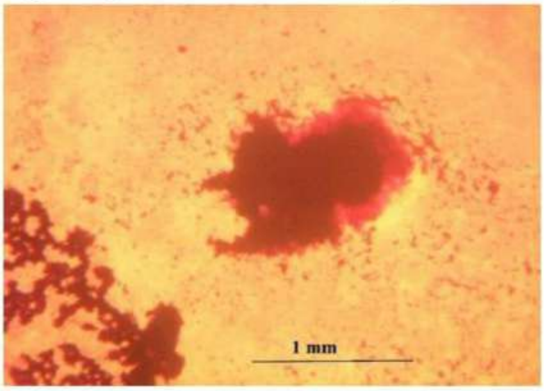
- Size < 98 ÷ 300 (µm)
- SVI_{30} < 135 ÷ 165 (ml/g)

Stage 2 (after 14 days)



- Size 1,5 ÷ 2,0 (mm)
- SVI_{30} < 108 (ml/g)

Stage 3 (after 21÷ 28 days)

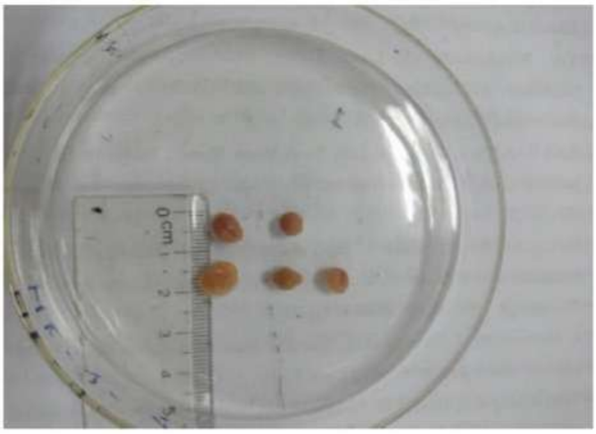


- Size 2,5 ÷ 2,9 (mm)
- SVI_{30} < 80 (ml/g)

Stage 4 (after 35 days)

- Size 3 ÷ 5 (mm)
- SVI_{30} < 65 (ml/g)

Stage 5 (after 42 ÷ 45 days)



- Size 3 ÷ 4 (mm)
- $SVI_{30} < 51$ (ml/g)

4.1.3. Microbiological composition of aerobic granular sludge

Basing on the results of microbiological analysis, we found that the number of microorganisms existing in aerobic granular sludge was much higher than that in the activated sludge. The microbial composition includes the main strains of bacteria such as: Aerobic bacteria, Anaerobic bacteria (acid-producing fermentation), Anaerobic bacteria (methane-producing)

4.1.4. Kinetics of aerobic granular sludge formation at organic load OLR 2.7÷3.0 (kgCOD/m³.day)

The kinetic equation of the aerobic granular sludge formation process:

$$D = 4{,}306(1 - e^{-0{,}03665t}) \quad (4.1)$$

In which: D - is the particle diameter (mm), t- is the time (days). Experimental results and kinetic models predict the formation and growth of aerobic granular sludge with a confidence level of 0.985, equivalent to 98%.

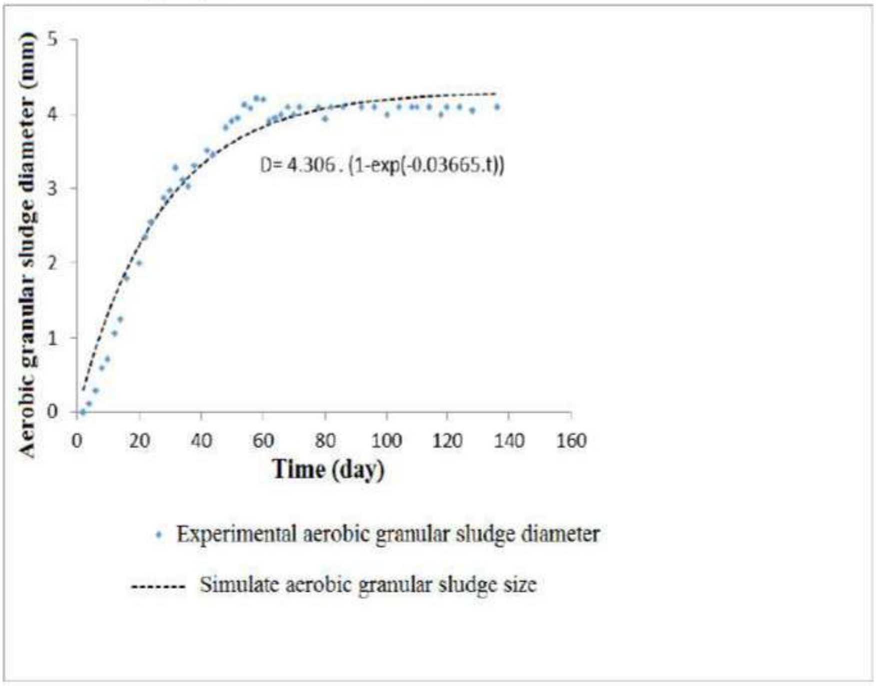


Figure 4.7. Kinetics of granular sludge formation and growth with OLR 2.7÷3.0 (kgCOD/m³.day)

4.1.5. Mechanism of aerobic granular sludge production on SBR technology model

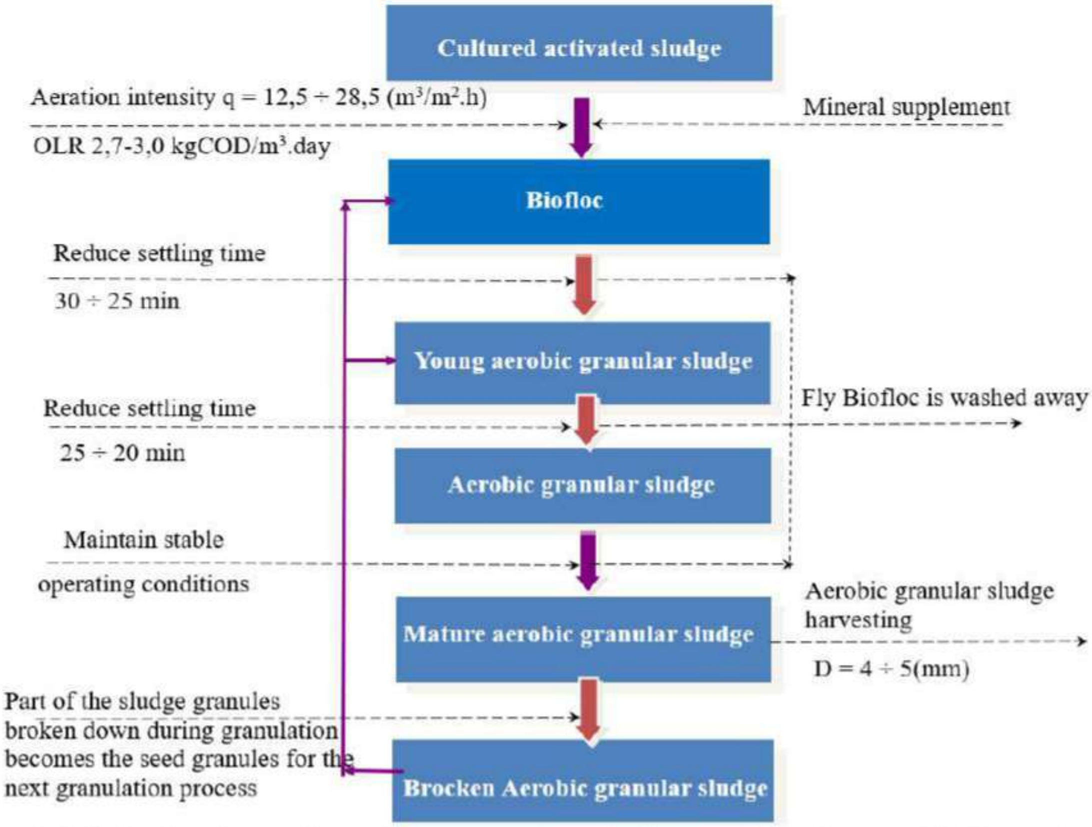


Figure 4.8. Mechanism of aerobic granular sludge production on SBR technology model

4.1.6. Discussion

From the results of culturing aerobic granular sludge on 2 models A and B, it shows the ability to form aerobic granule sludge for wastewater with low organic load from 1.0÷1.2 (kgCOD/m^3.day) is very difficult in model A. In the world, there have been studies on culturing granule sludge at organic load OLR < 2.0 (kgCOD/m^3.day) [85; 86]. This shows that culturing granular sludge with urban wastewater in Vietnam is difficult because most urban wastewater in Vietnam has low organic load.

In Model B, it was successful to culture aerobic granular sludge with an OLR of 2.7 ÷ 3.0 (kgCOD/m^3.day). The research results of the thesis are similar to many other studies in the same field in the country and in the world [5; 9; 12; 34; 69; 71).

It can be seen that, in Vietnam and in the world, there have been a number of successful research projects to produce aerobic granular sludge with different types of wastewater and different levels of organic loads, or to study other operating factors. However, the cultivation of aerobic granular sludge with urban wastewater in Vietnam in Model B of the thesis with OLR 2.7 ÷ 3.0 (kgCOD/m^3.day) under laboratory conditions has never been successful before. This is the new point of the thesis.

4.2. Evaluate the factors affecting the ability to form aerobic granular sludge and the ability to treat wastewater of aerobic granular sludge

4.2.1. Substrate composition

Substrate composition is the major factor to determine the dominant microbial composition in the aerobic granular sludge structure, and make the coloration of mature aerobic granular sludge. Aerobic granules fed with glucose or acetate substrates are in similar circular shapes. But the outer of glucose-cultured granule sludge was smoother than that of the acetate-cultured one because mycobacteria were more predominant.

4.2.2. Organic load

Organic load is one of the most important operational parameters in forming aerobic granular sludge and keeping sludge concentration stable. Studies around the world have demonstrated that the structure of biofilms is closely related to the organic loading [32]. The influence of organic loading on aerobic granular sludge formation can be in a very wide range from 2.5 ÷ 15 (kgCOD/m^3.day) [35]. Therefore, if the organic load is low, the aerobic granular sludge will find it difficult to maintain the biomass required for granulation. In contrast, the higher the organic load (OLR <15 (kgCOD/m^3.day)), the more rapidly the formation of granular sludge is stimulated [85].

4.2.3. Aeration flow

Aeration flow is a factor that directly affects the wastewater treatment efficiency of aerobic granular sludge. If the aeration flow is too large, the shear force acting on the granules will be large, which causes the granular sludge to break easily, and its structure to develop unstably, so the treatment efficiency will not be high. On the contrary, if the gas supply flow is too small, it will stimulate the growth of anaerobic microorganisms, so in the reaction tank aerobic microorganisms do not have enough biomass necessary to effectively treat wastewater as expected.

4.2.4. Aeration intensity

The factor of aeration intensity is very important to develop the diameter of sludge particle. If the intensity of aeration is too large, it will lead to grain breakage. Conversely, if the aeration intensity is too small, it will not be able to stir constantly the sludge particles, which causes the sludge to settle. Research results in model B show that the most favorable aeration intensity for aerobic granular sludge formation is q = 12.5 ÷ 28.5 (m^3/m^2.h). According to studies in the world, the safe aeration intensity to develop granular sludge is q = 6 ÷ 37 (m^3/m^2.h) [101; 102].

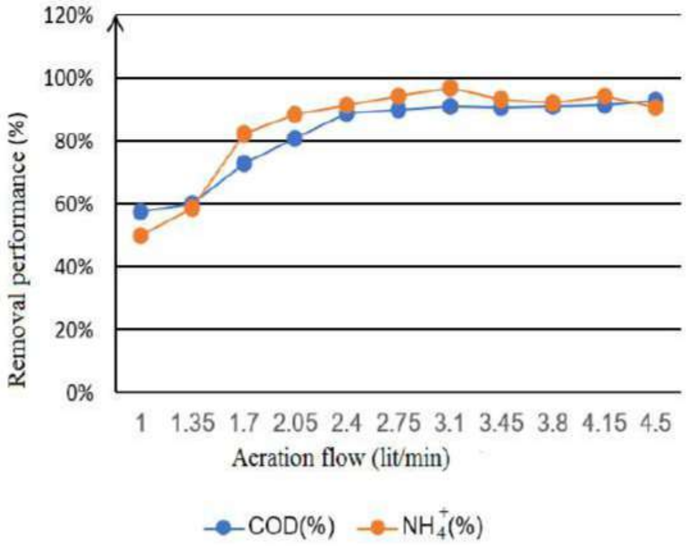


Figure 4.10. Relationship between aeration flow and treatment efficiency of aerobic granular sludge.

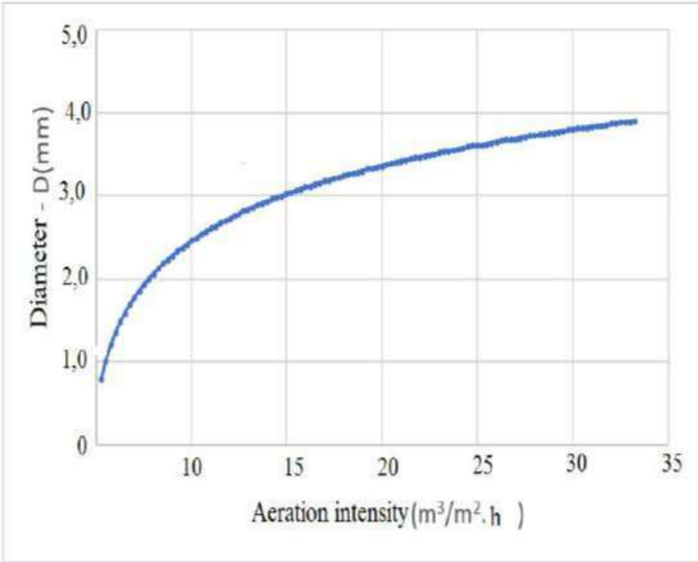


Figure 4.11. Relationship between aeration intensity and aerobic granular sludge diameter

4.2.5. Settling time

When the settling time is short, the sludge particles settling quickly will be selected, on the contrary, those with poor settling capacity can not settle, but drift with the water flow at the discharge phase.

4.2.6. Temperature

The ambient air temperature from 25 ÷ 35^{0}C hardly affects the treatment efficiency of aerobic granular sludge.

4.2.7. pH index

When the pH is lower, the treatment capacity of the granular sludge is poorer and less stable.

4.3. Results of removal of COD, NH_4^+-N, MLSS index and the ratio of MLVSS/MLSS, SVI_{30} during aerobic granular sludge culture

4.3.1. ***COD removal efficiency***

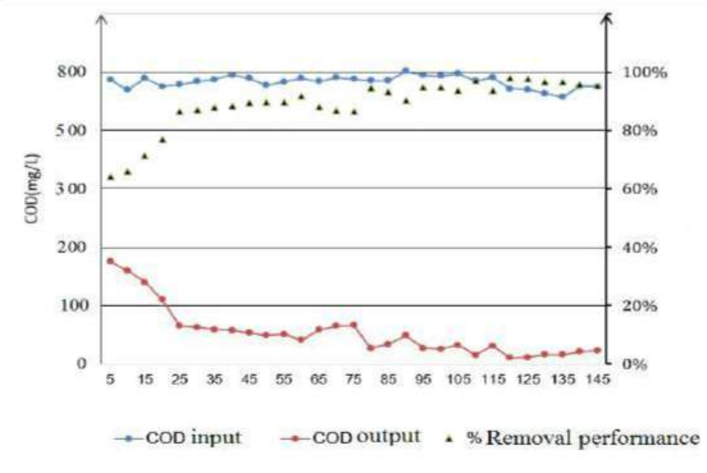


Figure 4.12. COD removal results

4.3.2. *NH_4^+ - N removal efficiency*

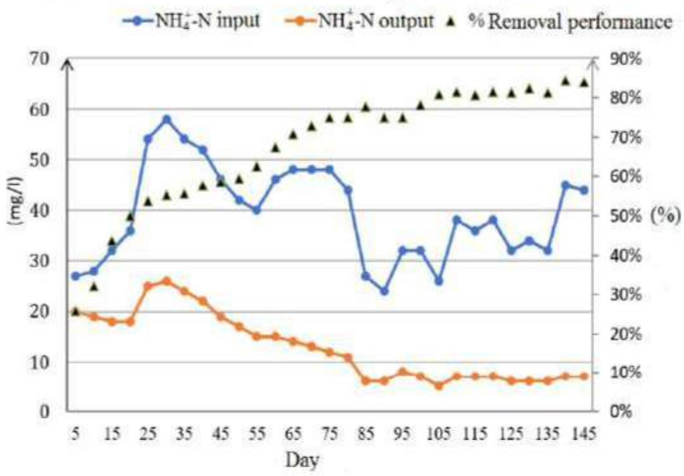


Figure 4.13. NH_4^+ - N removal results

4.3.3. MLSS index and MLVSS/MLSS ratio

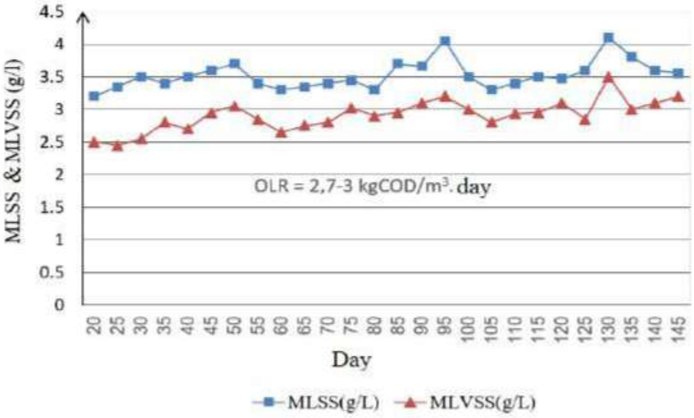


Figure 4.14. MLSS index and MLVSS

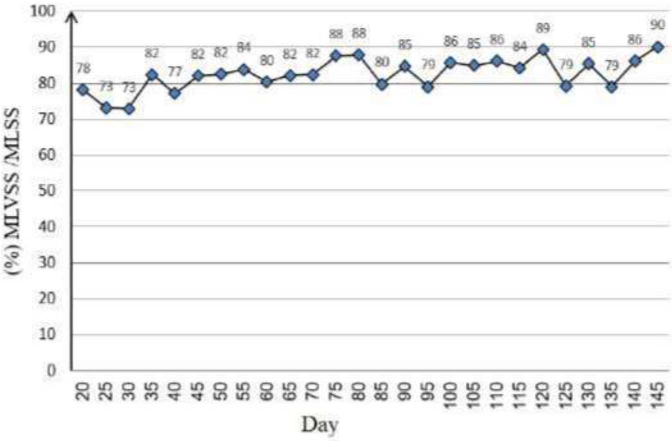


Figure 4.15. Variation (%)MLVSS/MLSS

4.3.4. SVI_{30} index

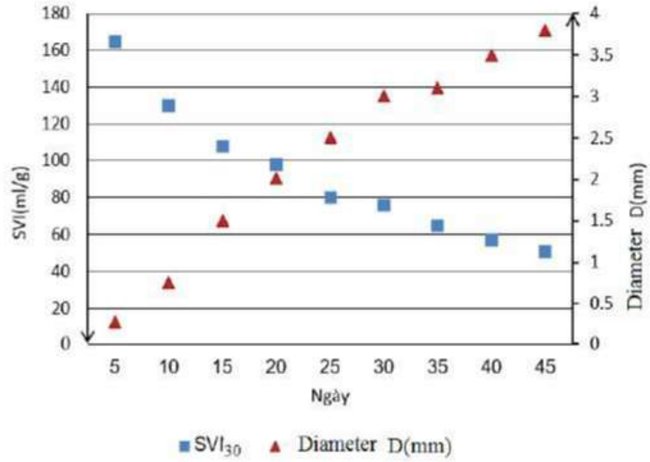


Figure 4.16. SVI_{30} variation and diameter of aerobic granular sludge

4.3.5. Discussion

a. COD removal process

In the aerobic granulation process, the granulation process and the removal of organic matter in the wastewater always take place at the same time. Research results show that the efficiency of wastewater treatment in the granular sludge formation is very good and increases gradually with the stability of the granular sludge system. The removal efficiency is over 95%COD when the system is stable. The research results on substrate treatment of the thesis compared with the results of domestic and foreign studies are similar. [5; 9; 34; 35; 99].

From the above comparison results, it can be seen that the results of COD removal in this thesis are very good, this will serve as a scientific basis for practical application in Vietnam.

b. NH_4^+ - N removal process

Similar to the COD removal process, the process of removing NH_4^+ - N in wastewater always occurs simultaneously with the aerobic culture process and the granulation process. The removal efficiency is over 84% NH_4^+ - N when the granular sludge system is stable.

Comparing the research results of the thesis with the results of domestic and foreign studies also gives similar results [5; 9; 34; 35; 99].

Like the resulst of COD removal , the above comparison results can prove that the NH_4^+ - N removal results of the thesis are very good, this will serve as a scientific basis for its practical applications in Vietnam.

c. Index MLSS and MLVSS

The analysis results of MLSS and MLVSS values fluctuated during the experiment, MLSS fluctuated at 3.2 ÷ 4.0 (g/l), MLVSS was 2.45 ÷ 3.2 (g/l), MLVSS/MLSS ranged from 73 ÷ 90%.

By comparing the results achieved by the thesis and the research results in the world, it can be seen that the MLSS value varies greatly depending on the types of wastewater and the organic load. The MLSS value of the thesis is stable at a lower level because the grain sludge has been harvested to carry out further studies.

4.4. Application of SBR technology using aerobic granular sludge to treat urban wastewater in Hanoi in the laboratory

4.4.1. Efficiency of removing organic and nutrients

a. COD removal efficiency

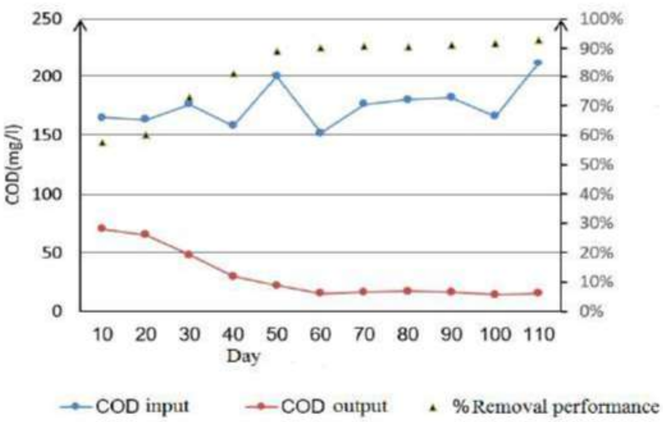


Figure 4.17. COD removal efficiency

b. NH_4^+ –N removal efficiency

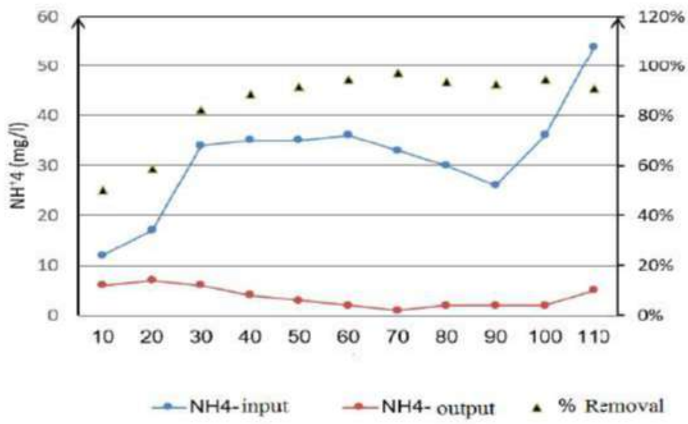


Figure 4.18. NH_4^+ -N removal efficiency

c. T–N removal efficiency

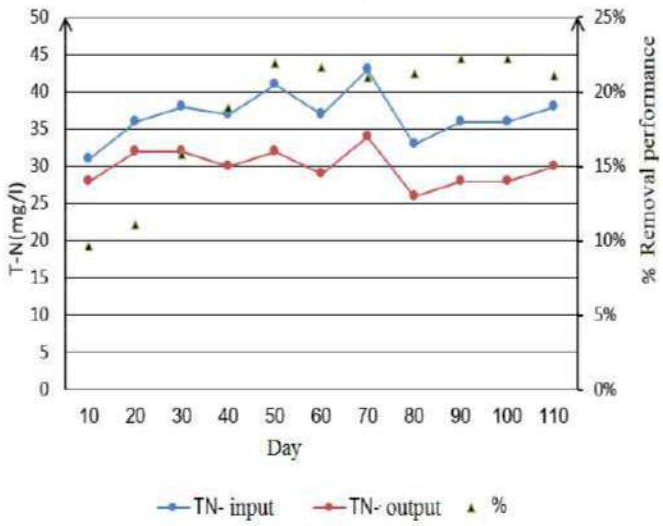


Figure 4.19. T–N removal efficiency

d. T–P removal efficiency

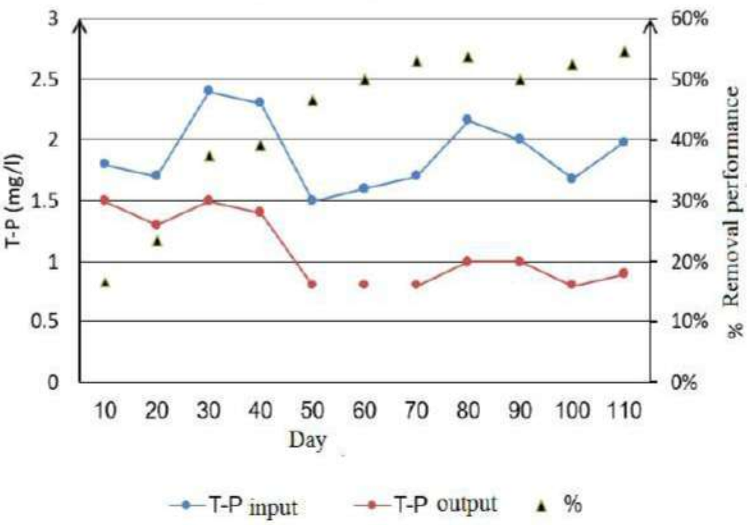


Figure 4.20. T–P removal efficiency

4.4.2. Evaluating the stability of the aerobic granular sludge culture process

a. MLSS sludge concentration and MLVSS/MLSS ratio

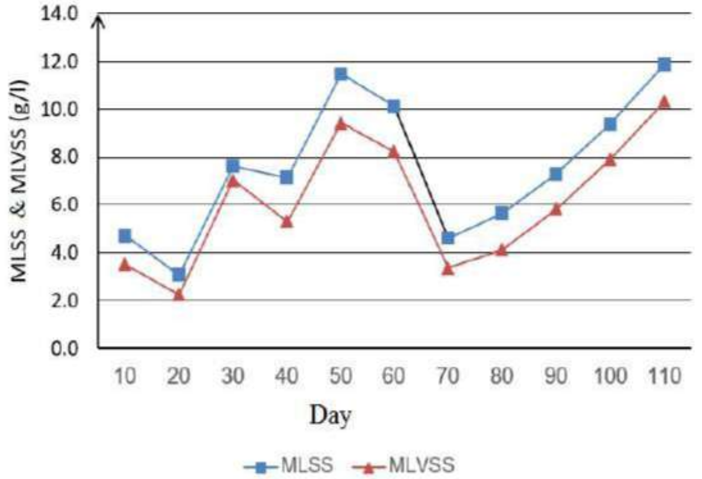


Figure 4.21. Changes in MLSS and MLVSS during the experiment

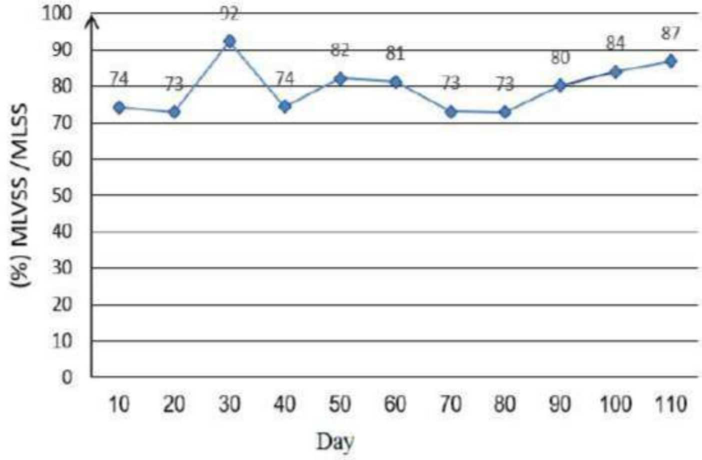


Figure 4.22. Changes in MLSS/MLVSS ratio

b. SVI_{30} index

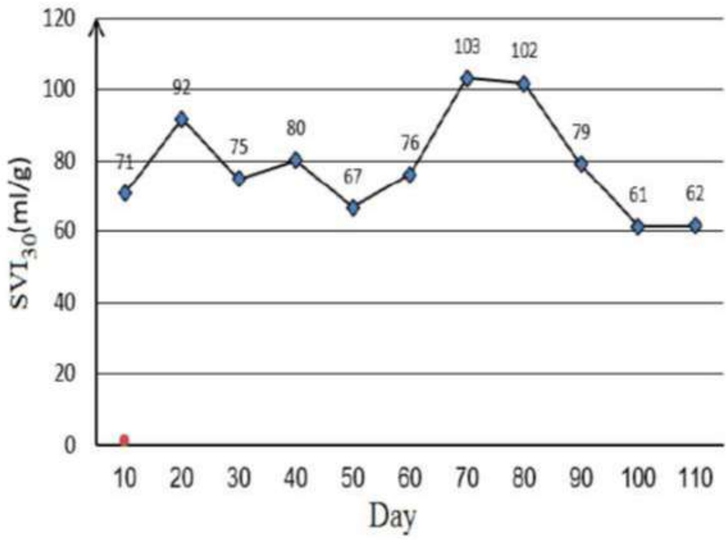


Figure 4. 23. SVI_{30} index during the experiment

4.4.3. Discussion

a. Stability of aerobic granular sludge

Urban domestic wastewater always contains many different organic compounds, organic substances such as nitrogen and phosphorus may be in the form of particles or dissolved. The properties of wastewater is not stable. It can be observed that small granular sludge does appear in the process of applying aerobic granular sludge on SBR technology model to treat urban wastewater. However, its fluctuations and instability over time makes the MLSS value change, the granular sludge is at risk of breakage due to the change in the organic load of the inlet wastewater. The process of starting the experimental model with municipal wastewater takes longer than with artificial wastewater. As a result, in 142 days of experimentation, the concentration of aerobic granular sludge gradually increased and stabilized [23].

b. Ability to remove nutrients in wastewater

At the beginning of the experiment, the aerobic granular sludge was not fully adapted to the urban wastewater environment in Hanoi, the efficiency of removing nutrients in the wastewater was not high and unstable, especially removing nitrogen and phosphorus. However, after that, when the aerobic granular sludge system in the SBR tank operated more stably and the SRT sludge retention time increased, the efficiency of nutrient removal was also higher and more stable. The efficiency of T-P and T-N removal is low due to carbon available during the anaerobic period. Therefore, the denitrification process is not very efficient, and the carbon absorption reduces significantly.

Experimental results show that the application of aerobic granular sludge for urban wastewater treatment in Vietnam on the SBR technology model is feasible because the COD and NH_4^+ - N treatment efficiency is consistent with current Vietnamese standards . The average COD removal efficiency is over 90%, NH_4^+ - N is over 80% when the model reaches steady state, which is a good result. However, the results of T-N removal of 20 ÷ 21% are only moderate and low, which shows that there are still many problems to address for the application of aerobic granules in the model SBR technology to treat urban wastewater with low organic load in Vietnam.

4.5. Evaluation of the effectiveness of SBR technology application using aerobic granular sludge to treat urban wastewater and its applicability in practice

4.5.1. Evaluation of the ability to process the substrate

The ability to treat substrate by using aerobic granular sludge on SBR technology model for urban wastewater treatment has been demonstrated through the experimental results of the thesis. The efficiency of removing nutrients BOD_5, COD, NH_4^+ - N is quite high compared to the current standard system in Vietnam and some wastewater treatment plants that are applying traditional activated sludge technology in Vietnam.

From the survey and comparison results, it can be seen that the substrate removal efficiency of typical wastewater treatment plants in Vietnam varies greatly, depending on the applied technology and substrate concentration of input wastewater. Although wastewater treatment plants all treat urban wastewater with a low load, the BOD_5, COD, NH_4^+ - N, T-N, T-P removal efficiency of wastewater treatment plants and in this thesis all meet Vietnam standard for urban wastewater 14/2008 and 40/2011. This proves that the use of aerobic granular sludge on SBR technology model to treat urban wastewater in Vietnam is feasible. However, in order to be widely applied in practice, it is necessary to have a lot of researches on the influencing factors when transferring technology from the laboratory to the field. Because of the limitations of the thesis, it is not possible to study all of them. In addition, in order to apply aerobic granular sludge to urban wastewater treatment, it is necessary to introduce a technological chain diagram suitable for typical wastewater conditions in Vietnam.

4.5.2. Assess the ability to apply research in practice

From the results of the actual survey at urban wastewater treatment plants in Vietnam and the analysis, comparison of the experimental results of the thesis, it can be seen that the application of aerobic granular sludge on the SBR technology model to treat dilute urban wastewater in Vietnam bases on scientific basis for the following reasons:

- The BOD, COD, NH_4^+ - N removal efficiency is stable and high when making comparison between wastewater treatment plants applying the SBR technology and those using other technologies.
- Suitable for urban wastewater with low organic load. Most urban areas in Vietnam currently use a common sewer system , so wastewater has a low organic load.
- Wastewater treatment plants applying SBR technology are very popular in Vietnam, so it will be very convenient to apply aerobic granular sludge on the SBR technology model.

However, the actual application of SBR technology using aerobic granular sludge to treat dilute urban wastewater in Vietnam also has the following limitations:

- It is dificult to cultivate aerobic granular sludge and maintain its concentration in wastewater with low organic load.
- The removal efficiency of T-N is not high, only medium or low, which is a difficult problem for all types of wastewater treatment technologies in Vietnam due to the characteristics of low organic urban wastewater in Vietnam.

4.5.3. Proposing aerobic granular sludge application technology for urban wastewater treatment in Vietnam

a. The case for dilute urban wastewater with OLR<2.0 (kgCOD/m³.day)

In this case, it is difficult to successfully grow the granular sludge and maintain the sludge concentration in the reactor. Therefore, on the technology diagram, it is necessary to have additional solutions and maintain a stable particle sludge concentration. The granular sludge will be raised in a separate tank with the appropriate addition of nutrients and COD. The amount of granular sludge that needs to be added includes dissolved and washed sludge, old sludge. The addition of granular sludge to always ensure the required F/M ratio. The diagram looks like Figure 4.24.

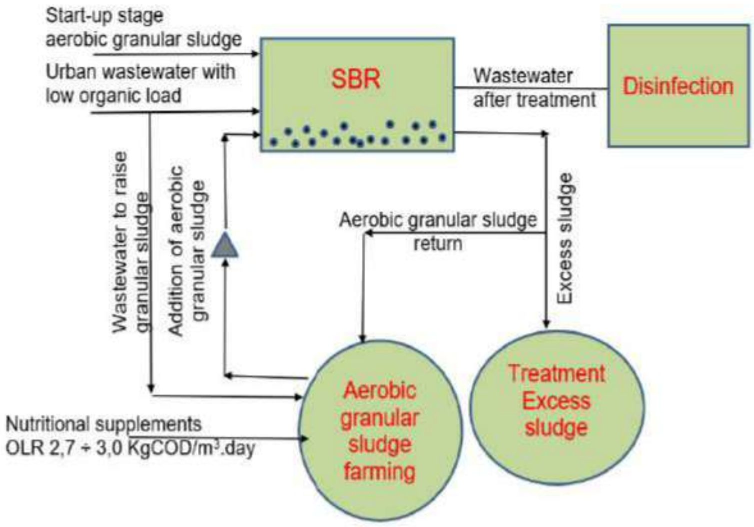


Figure 4.24. Technological line diagram for application of aerobic granular sludge on SBR technology to treat urban wastewater with low organic load

b. The case for solid urban wastewater with OLR > 2.5 (kgCOD/m^3.day)

For urban wastewater with high organic load, the concentration of granular sludge is always ensured due to the sludge formation process right in the reactor. On the technology diagram, there is no need to have additional solutions and maintain the particle sludge concentration to always ensure the required F/M ratio. The diagram looks like Figure 4.25.

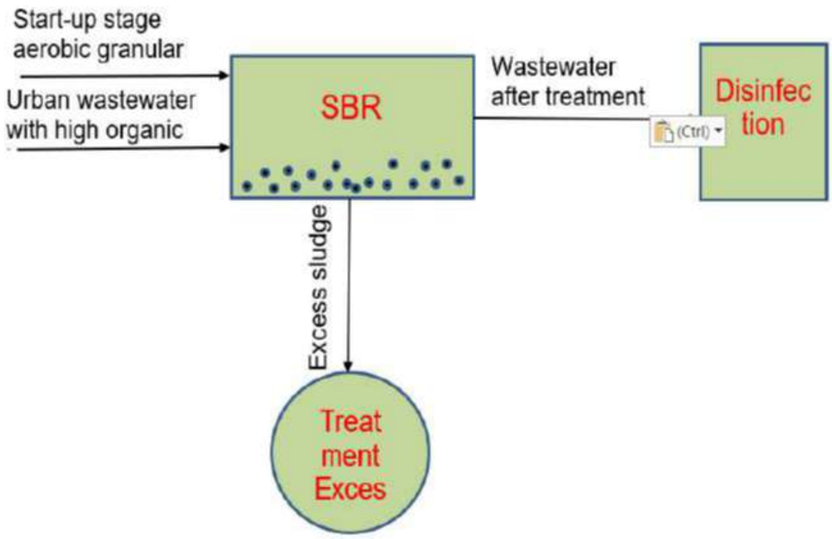


Figure 4. 25. Technological flow diagram for application of aerobic granular sludge on SBR technology to treat urban wastewater with high organic load

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The thesis " Research on SBR technology using aerobic granular sludge to treat urban wastewater" has drawn the following conclusions:

1. The process and technical parameters of successfully culturing aerobic granular sludge in SBR tanks for wastewater with high organic load have been determined in a laboratory in Vietnam. In the thesis, the aerobic granular sludge was cultured with

organic load of 2.7 ÷ 3.0 ($kgCOD/m^3$.day), optimal aeration intensity for the stabilization of aerobic granular sludge. is q = 12.5 ÷ 8.5 (m^3/m^2.h). This result is consistent with studies in the world that only successfully cultured aerobic granular sludge with organic load of 2.5 ÷ 15 ($kgCOD/m^3$.day) [35], aeration intensity q = 6 ÷ 37 (m^3/m^2.h) [101; 102]. Specifically:

+ The successful sludge culture time is 35 ÷ 45 (days) for the sludge to reach a stable and mature size.
+ The size of the mature aerobic granular sludge is d = 3 ÷ 4 (mm).
+ Aerobic granular sludge has spherical shape, yellow-brown color, solid granular structure when mature.
+ $SVI_{30} < 51$ (ml/g).

2. The ability to remove (treat) organic substances (COD; NH_4^+ - N; T-N; T-P) has been evaluated on the SBR technology model to treat urban wastewater with low organic load (wastewater collected at Kim Lien wastewater treatment station – Hanoi), Specifically:

+ COD decreased from 212 (mg/l) to 17 (mg/l). COD removal efficiency is over 92%.
+ NH_4^+ - N decreased from 40 (mg/l) to 8 (mg/l). NH_4^+ - N treatment efficiency is over 80%.
+ T-N decreased from 38 (mg/l) to 28 ÷ 30 (mg/l). T-N treatment efficiency from 20% ÷ 21%.
+ T-P decreased from 1.98 (mg/l) to 0.8 ÷ 1.0 (mg/l). T-P treatment efficiency from 50% ÷ 52%.
+ The cause of the low efficiency of T-N and T-P treatment for many reasons that cannot be fully evaluated within the scope of the thesis.

3. The research results of the thesis show that the possibility of applying SBR technology using aerobic granular sludge to treat urban wastewater has a scientific basis for the following reasons:

+ The COD, NH_4^+ - N removal efficiency is stable and high efficiency when compared to other wastewater treatment plants applying SBR technology in Vietnam and compared with current discharge standards in Vietnam (Vietnam standard 14/2008-BTNMT and 40:2011/BTNMT)
+ Suitable for urban wastewater with low organic load, since most urban areas in Vietnam use a common drainage system, wastewater usually has a low organic load.
+ Wastewater treatment plants in Vietnam applying SBR technology are very popular, the application of aerobic granular sludge on the SBR technology model is very convenient.

However, the treatment (removal) of T-N is not high, so the widespread application of aerobic granular sludge on the SBR technology model for urban wastewater treatment in Vietnam requires more time and other studies.

RECOMMENDATIONS

For aerobic granular sludge process on SBR technology model:

1. Research has successfully raised aerobic granular sludge in the laboratory at high organic loading. Therefore, it is recommended to add the granular sludge culture method of the thesis to the list of aerobic granular sludge culture methods.
2. Research has determined the removal efficiency of COD, NH_4^+ - N of the application of aerobic granular sludge on SBR technology model for urban wastewater treatment in Hanoi. Therefore, it is recommended to further research the application of the above technology with other types of wastewater.
3. There should be studies to improve the treatment efficiency of T-N with the application of aerobic granular sludge on the SBR technology model to treat urban wastewater with low organic load.

For the application of aerobic granular sludge on the SBR technology model for urban wastewater treatment:

1. The research only stops at aerobic granular sludge farming and application of aerobic granular sludge on SBR technology model to treat urban wastewater in Hanoi with low organic load in laboratory scale, to be able to apply effectively in practice, it is necessary to have studies on the influencing factors when moving from the laboratory to practical application.
2. Research on the application of aerobic granular sludge on SBR technology model for many different types of wastewater and on a larger scale to evaluate the influence of different types of wastewater on the stability of granular sludge aerobic in practice.

LIST OF SCIENTIFIC WORKS PUBLISHED BY AUTHOR RELATED TO THE THESIS

1. Pham Van Doanh, Tran Thi Viet Nga, Nguyen Binh Minh (2021), "Forming aerobic granulation on SBR technology at the laboratory" *Vietnam Journal of Science, Technology and Engineering*, ISSN 1859 – 4794, DOI: 10.31276/VJST.64(1).01-05.
2. Pham Van Doanh, Tran Thi Viet Nga, Nguyen Binh Minh (2021), "Application of aerobic granulation in SBR technology to treat low-strength urban wastewater" *Vietnam Journal of Science, Technology and Engineering*, ISSN 1859 – 4794, DOI: 10.31276/VJST.63(11).16-20.
3. Pham Van Doanh, Tran Thi Viet Nga, Nguyen Binh Minh (2021), "Evaluating the influence of factors on the wastewater treatment by application of aerobic granulation in SBR technology", *Journal of Materials and Construction*, ISSN 1859 – 381X, 5(2021).62-66.
4. Pham Van Doanh (2019), "Overview of research on sbr technology using aerobic sludge to treat urban wastewater", *Viet Nam Journal of Construction*, ISSN 0866 – 8762, 621, 239 – 241.
5. "Research and application of improved SBR technology using aerobic granular sludge to treat urban wastewater in Vietnam" , *Scientific research project of the Ministry of Construction*, code RD 53-19, Tran Thi Viet Nga .