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Bio-regeneration for Sodium Silicate Used Sands and its Unattended Monitoring System

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Abstract

Sodium silicate, known for its low cost and non-toxicity, has been considered as a promising option for green foundry in terms of mould sands. However, the utilization of used sodium silicate sands has posed significant challenges. To address the issues of high energy consumption and secondary pollution associated with wet and dry regeneration of sodium silicate used sands, this paper proposes a novel unattended biological regeneration system. The system involves culturing diatoms in an incubator with a solution of sodium silicate used sands. The incubator is equipped with built-in sensors that continuously monitor temperature, illuminance, pH, and water level. The monitoring data is transmitted in real-time to the Yeelink Internet of Things platform via the controller using the TCP/IP protocol. By logging onto the corresponding web page, the experimenter can remotely observe the monitoring data. The results of the experiment indicate that diatoms bloomed five times, and the water pH decreased from 10.2 to 8.2 after 40 days of cultivation. Additionally, the film removal rate of the used sands reached 90.26%.

Keywords: Sodium silicate used sands, Diatom, Water bloom, Internet of Things platform

1. Introduction

Sodium silicate is currently the most successful inorganic chemical binder for long-term use in the formation of sodium silicate sands. It is cheap, has easy fluidity, fast hardening, and high dimensional accuracy of the mould cores [1]. However, a major problem arises when it comes to the disposal of used sodium silicate sands. Many factories dispose of these sands directly into rivers, valleys, and oceans, causing damage to the vegetation. Moreover, the soluble alkaline sodium silicate and other harmful substances present in these used sands can contaminate surface and groundwater sources, leading to serious environmental pollution. Therefore, finding environmentally sound disposal methods for sodium silicate sand has become increasingly critical [2]. This chapter of the literature survey focuses on the traditional regeneration processes, namely wet regeneration, dry regeneration, and chemical regeneration [3-4]. Dry regeneration generates dust during the process and suffers from issues such as abrasion, power consumption, and lengthy mulling periods, making it less efficient and economical compared to other methods. Wet regeneration, on the other hand, involves complicated equipment systems, high energy and water consumption, and the need for sewage treatment and sludge disposal. In the past, some wet regeneration installations failed to meet expectations because the designers assumed that water alone would be sufficient to remove the binding film from used sand grains. However, it was found that simply washing the used sand

mass was not enough. Chemical regeneration, while an option, has its limitations as it cannot distinguish between harmful and harmless residual Na_2O during the regeneration process, potentially leading to more serious Na_2O accumulation [5].

It requires further clarification and chemical treatment and, depending on local industrial wastewater requirements, may also require treatment prior to discharge into the local wastewater system, increasing the cost of the process. Today, the development of biotechnology, especially diatom biotechnology, gives hope to explore new methods of reusing waste sodium silicate sands and solve the problem of reusing waste sodium silicate sands once and for all. This project designed the control system for the regeneration of used sodium silicate sand with the main aim of accelerating the biological regeneration of sodium silicate, and achieved unattended operation by adopting the Internet of Things platform, which significantly reduced the workload of the experimental personnel.

The sodium silicate binder in the used sands was continuously released, allowing diatoms to reproduce quickly by controlling the parameters. The proliferation of diatoms will further enhance the dissolution of sodium silicate, ultimately leading to the transfer of sodium silicate from the surface of the used sands to diatoms. The proliferation of diatoms results in the absorption of a significant quantity of sodium silicate, which can then be harvested using specialized equipment for the production of fertilizers. This process not only saves labor but also promotes safety and environmental sustainability. The schematic diagram illustrating the biological regeneration method of sodium silicate used sand can be found in Figure 1.

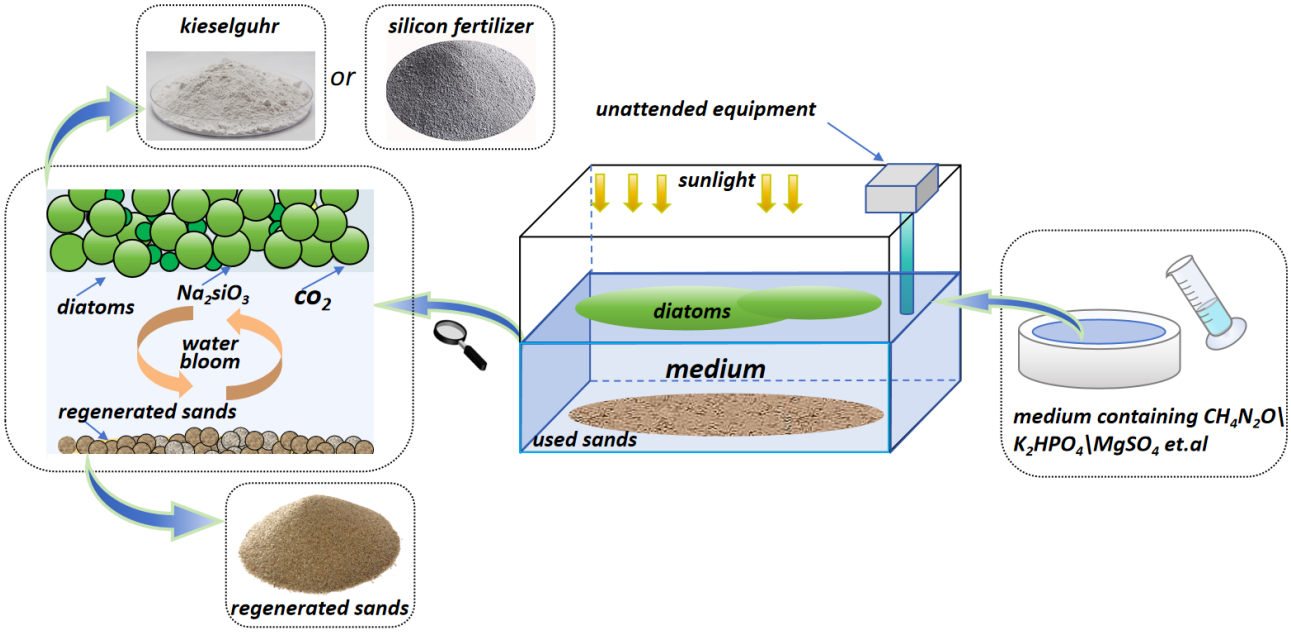

Fig. 1. Bio-regeneration method for sodium silicate used sands

2. Materials and Methods

Soluble silicate was the most abundant component of the diatom medium besides the nitrogen source and was required for the formation of silicate cell walls to protect the luminal tissue during diatom bloom [6]. After casting, 55% to 65% of the Na_2O in the soluble silicate used sands was present in the dehydration and high-modulus sodium silicate solution, which was soluble and can be converted back to the sodium silicate solution state through realkalization and rehydration.

The carbon dioxide hardened sodium silicate sands came from the Welfare Comprehensive Processing Plant of Hubei Special Steel, Wuhan Iron and Steel Co., Ltd., and the added amount of sodium silicate was 8%. The factory sands had not been broken, so the surface sand was clearly distinguishable (about 10% of the total weight of the used sand, the distribution was more concentrated, the surface color of the quartz sand had become white due to the formation was composed of glass-like substances, and broke after soaking in water basically not) and the return sands (about 90% of the total weight of the used sands), the surface color of the quartz sands was darker than that of the surface sand, and after soaking in water, it quickly broke down into fine sands. In the test container, 20 kg of water, 10 kg of used sands, and a diatom culture medium were added.

2.1. Research of the species of diatoms

To speed up the regeneration process, *Navicula*, *Asterionella*, *Melosira* and *Synedra* were used in the experiment. These four species of diatoms occurred in the middle and lower reaches of the Yangtze River. The diatom species were provided by the Freshwater Algae Culture Collection at the Institute of

Hydrobiology, (FACHB) of the Institute of Aquatic Biology of the Chinese Academy of Sciences. These were excellent species of algae with great economic value in aquaculture. They can be used as bait or directly produce silicon fertilizer. The microscopic view of these diatoms was shown in Figure 2.

Fig. 2. The microscopic view of *Navicula*, *Asterionella*, *Melosira* and *Synedra*

2.2. Research of diatoms culture medium suitable for the system

Diatom's reproduction also needed other nutrients. Therefore, we had prepared a medium that was conducive to diatoms reproduction. The diatoms medium used in this experiment, the silicon source was provided by the soluble residual binder in the sodium silicate sands. The concentration of medium (D1) given by FACHB was shown in Table 1. In this experiment, D1 diatom culture medium was used, and the silicon source was provided by the soluble residual binder in the used sodium silicate sands. The sodium nitrate nitrogen source was changed to urea. The composition of the A5 medium was illustrated in Table 2. Diatoms from FACHB were inoculated into a 5ml Erlenmeyer flask that had been sterilized at 115 ℃. The ratio of the four diatoms was maintained at 1:1:1:1, as shown in Figure 3.

Table 1.
Composition of D1diatoms medium

Substance	Content
CH_4N_2O	0.04 g/L
K_2HPO_4	0.04 g/L
$MgSO_4$	0.07 g/L
$CaCl_2$	0.02 g/L
KH_2PO_4	0.08 g/L
$MnSO_4$	0.0002 g/L
$FeC_6H_5O_7$	0.005 g/L
water	20ml
A5	1ml

Table 2.
Composition of A5 diatoms medium

Substance	Content
H_3BO_3	2.86 g/Ld H_2O
$MnCl_2{\cdot}4H_2O$	1.86 g/Ld H_2O
$Na_2MoO4{\cdot}2H_2O$	0.39 g/Ld H_2O
$CuSO_4{\cdot}5H_2O$	0.08 g/Ld H_2O
$ZnSO_4{\cdot}7H_2O$	0.22 g/Ld H_2O
$Co(NO_3)_2{\cdot}6H_2O$	0.05 g/Ld H_2O

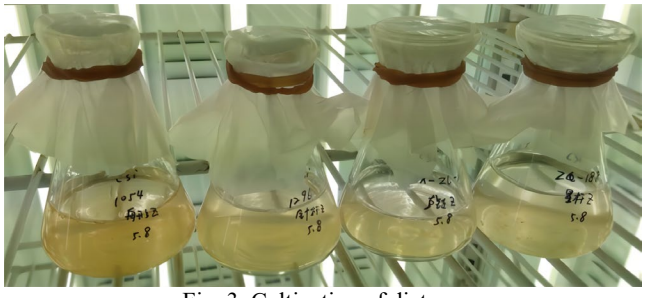

Fig. 3. Cultivation of diatoms

2.3. Different temperatures, nitrogen, phosphorus, and potassium on diatom blooms

Under specific conditions (water rich in nitrogen, phosphorus, and other nutrients, with a total phosphorus content of 0.087 mg/L or higher, total nitrogen content of 0.78 mg/L or higher; in enclosed water bodies with a flow rate of less than 0.8m/s; water temperature above 10°C; and light levels between 5000-15000 lux), diatoms are likely to experience blooms in the water [7].

The diatoms will gather in clumps and float on the surface of the water, causing a natural stratification of diatoms and reclaimed sands, which can easily be achieved by mechanical salvage of most diatoms and sands. When diatoms blooms, the water becomes discolored and emits a foul odor, negatively impacting aquatic organisms. Timely salvage can mitigate the effects of diatom bloom. This system includes a diatom recycling function, which can solve the problems. The preparation of sodium silicate by living diatoms or silicon fertilizer can learn from the preparation technology of sodium silicate based on kieselguhr [8]. It was also common to directly use diatoms to prepare valuable shellfish and fish bait, silicon fertilizer, diatom mud and other aspects.

The effects of environmental factors on the growth of diatoms under laboratory light incubator conditions were examined using constant culture. Culture days were every 7 days and biomass were measured with a spectrophotometer. The growth of diatoms under different nitrogen concentrations, phosphorus concentrations, potassium concentrations and temperatures were compared.

As shown in Figure 4, when the temperature of diatoms was 25 °C, their growth was superior compared to other temperatures, leading to more vigorous life activities. As shown in Figure 5, when the concentration of nitrogen was 80mg / L, the growth of diatoms was the best.

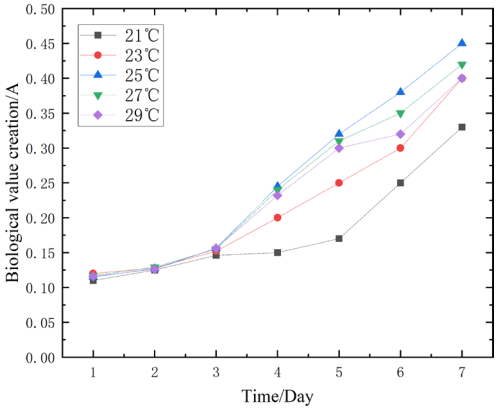

Fig. 4. Temperature on the growth rate of diatoms

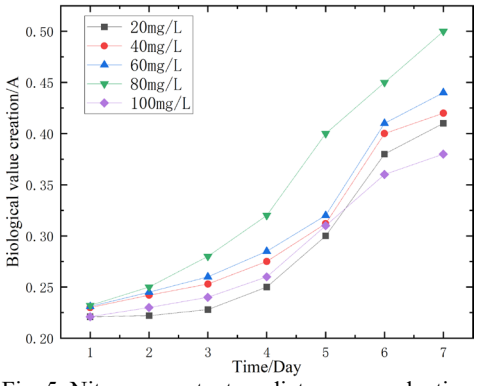

Fig. 5. Nitrogen content on diatoms reproduction

As shown in Figure 6, the growth state of diatoms reached its peak when the phosphorus concentration was 50mg/L. Subsequently, there was no significant change in the growth state of diatoms with further increases in phosphorus concentration.

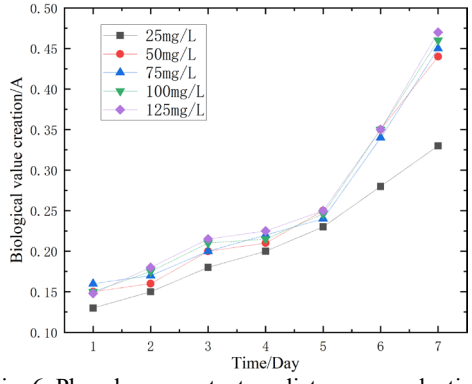

Fig. 6. Phosphorus content on diatoms reproduction

As shown in Figure 7, the growth of diatoms was optimal when the potassium concentration was 30mg/L. However, the growth of diatoms was slowed down by the phosphorus concentration when it ranged from 50mg/L to 90mg/L.

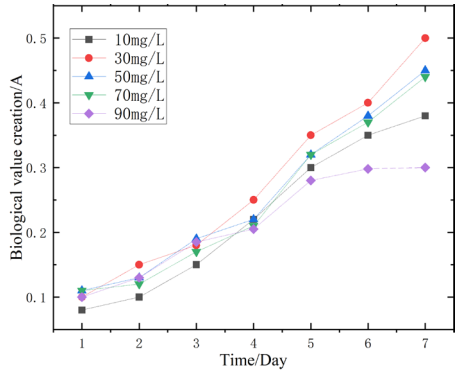

Fig. 7. Potassium content on diatoms reproduction

The data of the above factors can be analyzed centrally to obtain the most suitable value for diatoms reproduction, and the number of factors added can be controlled by the equipment to optimize the diatoms reproduction.

Experiments on diatom culture had shown that the proliferation rate of diatoms is inextricably linked to environmental factors such as temperature, illumination level and nutritional factors such as nitrogen, phosphorus, and potassium etc. Temperature and illumination levels had a much greater impact on diatom dispersal rates than nutrient concentrations, so it was important to control illumination levels and temperature during diatom growth [6].

2.4. Regeneration system design for sodium silicate used sands

Based on the above experiments, an unattended control system for the biological regeneration of used sands in the sodium silicate was developed for this project. As the project was implemented in an open environment, the illuminance intensity that affected the growth of diatoms was not controlled but observed. The STM32 micro-controller was used as the controller and the ESP8266 module was added to the controller design to allow the controller to access the network [9]. A variety of sensors such as the temperature, illuminance, water level and pH conditions that affect the survival of diatoms in the system in real time, and thermostat and water level control devices enable the diatoms to survive under suitable conditions.

The PT100 sensor (Fig.8(a)) was chosen as the temperature sensor for the system, transmitting the collected temperature signal to the STM32 controller. When the temperature of the culture medium deviates by 1 ℃ from the programmed temperature, the STM32 adjusted the temperature by regulating the relay G1 (Fig.8(i)) to increase or decrease, maintaining the temperature within the preset range. The HA2003 sensor (Fig.8(b)) was used as the illuminance sensor. HA2003 monitors the illuminance intensity in real time, and sends the collected optical signal to the controller STM32 after amplification and processing to obtain accurate real-time illuminance intensity values. The GY100 sensor (Fig.8(c)) was used as the pH sensor to detect the pH value of the solution.

When the experimenter observed the diatoms flooding into the water in the experimental container through the PC or mobile terminal, the diatom pump motor activated. This led to the introduction of the diatoms from the experimental container into the diatom storage tank. The HC-SR04 sensor (Fig.8(d)) was used as the water level sensor to transmit the real-time monitored water level signal to STM32; meanwhile, by controlling the relay G2 (Fig.8(h)) to make the inlet/outlet water pump work when the water level in the experimental vessel deviated from the set value, the water level was restored to the set value.

At the same time the IoT platform (Fig.8(e)) was introduced and the data detected by the sensors would be transmitted to the server via TCP/IP protocol. The system can be accessed via a PC or mobile phone with a corresponding web page, which not only provides access to real-time monitoring data and real-time images (Fig.8(j)), but also allows remote control of the controller, the automatic recycling of diatoms (Fig.8(g)) was realized by simply touching the button. At the same time, real-time upload of sensor data could be accomplished by means of Internet of things platform [10-11]. Experimenters could log on to the corresponding web page to observe the monitoring data of the system in real time and achieved remote control of the system by adding the corresponding modules to the platform.

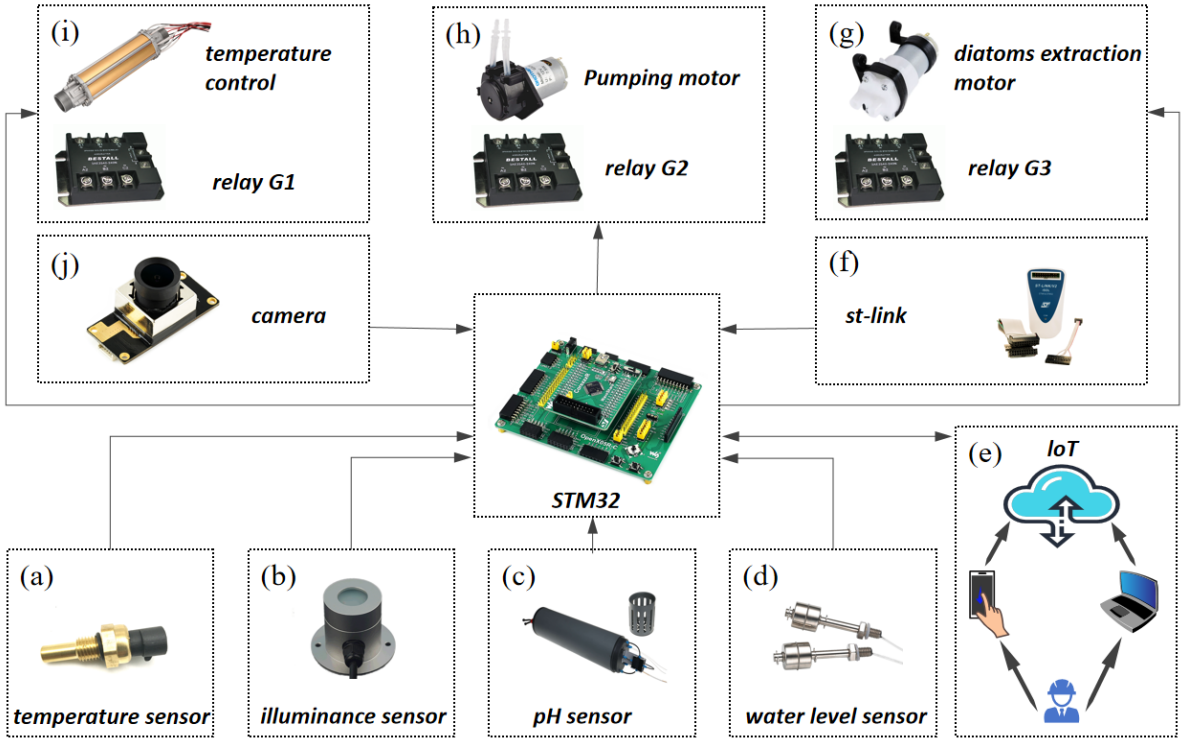

Fig. 8. Regeneration system for sodium silicate used sands

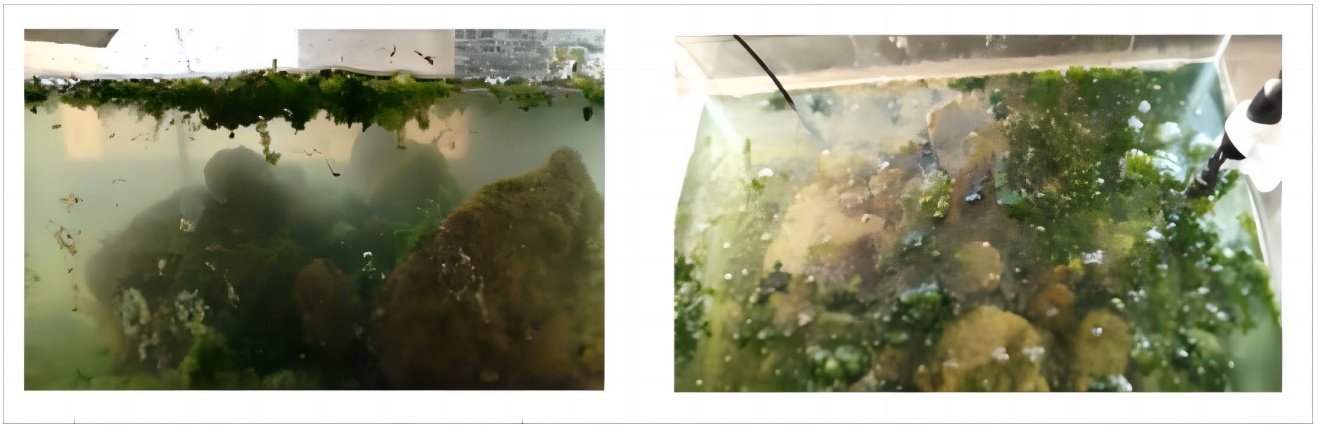

Fig. 9. The bloom phenomenon of diatoms

3. Results and analysis

Cultivation of diatom in the designed regeneration control system, the water source used easily accessible groundwater, Since the majority of the substance in the medium was water, the water to sand ratio of the aqueous solution was approximately 2:1. The monitoring data of the regeneration control system in the diatom culture process were obtained through the Yeelink platform, and shown after 40 days of cultivation, the diatoms had 5 water blooms in this system. Side and top views of diatoms blooms were in Figure 9. The data was obtained from the built-in sensors of the control system obtained from the Yeelink platform, as shown in Figure 10. They showed the illuminance of the diatom over a 24-hour period on a given day of the culture cycle (the illuminance over the 40 days of the culture cycle roughly corresponds to this distribution).From the results in Figure 11, it was clear that the temperature change on a given day during the cultivation cycle of the solution in the regeneration control system with the temperature remaining near 25℃. This shown that the temperature control system met the requirements in the experiment. As shown in Figure 12, it was depicted the change in the water level of the solution in the regeneration control system throughout the culture cycle of the diatoms, with the water level remaining around 50cm, indicating that the water level control system met the requirements in the experiment.

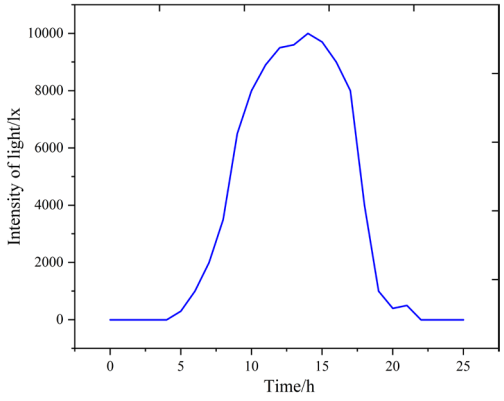

Fig. 10. The degree of change in illumination

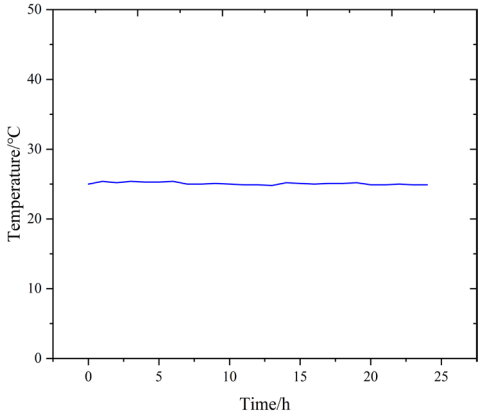

Fig. 11. The degree of change in temperature

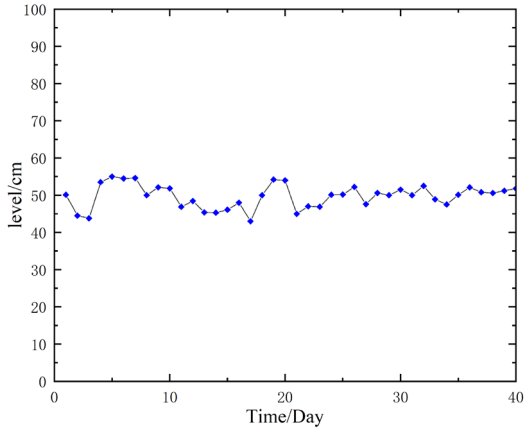

Fig. 12. The degree of change in water level

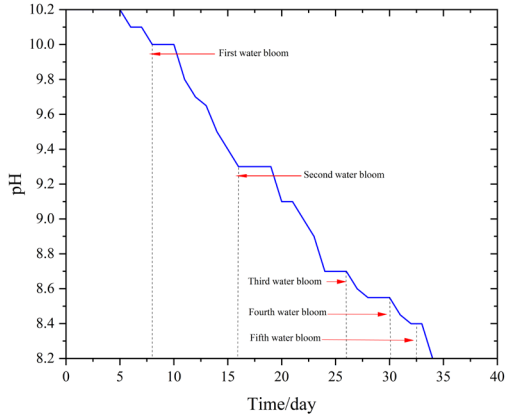

Fig. 13. The degree of change in pH

As shown in Figure 13, the pH of the solution gradually decreased from the initial 10.2 to 8.2. During the whole process, a total of 5 water blooms occurred. Combined with the bloom phenomenon in Figure 9, it was shown that diatoms consumed a large amount of soluble silicate during rapid reproduction, it caused the pH of the solution to drop，and the results met the sewage discharge standards.

To further prove the reliability of the pH indicator data, the experimenter had extracted a portion of the solution each day and used the traditional hydrochloric acid titration method to determine the sodium silicate content in the solution. The results are shown in Figure 14.

Figure 14 showed the change trend of sodium silicate in the culture system during the regeneration of used sodium silicate sands. When reacting free sodium oxide in the culture system, the more sodium oxide was present, the larger the titration volume was. The sodium oxide was separated after the diatoms absorbed the silicon on the surface of the used sands. Therefore, the larger the volume of hydrochloric acid, the higher the recovery rate of sodium silicate. It can be seen from the figure that the recovery rate of sodium silicate was not high in the first 6 days of the culture system. The recovery rate of sodium silicate increased sharply in the period from 6 to 18 days, and the recovery rate of sodium silicate continued to decrease after 18 days.

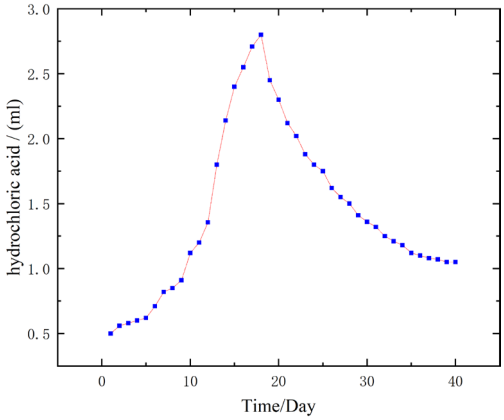

Fig. 14. The degree of change of sodium silicate content

Enriched diatoms on the surface of the water body were treated with the collection device, and then the nutrients were supplemented according to the salinity reduction rate (α) of the salinity sensor and the residual water volume (V). The addition amount of each nutrient was multiplied by $\alpha \cdot V$.

The proportion of remaining sodium silicate in the aqueous solution after standing for a time was measured. And the use of the above ratio to carry out the calculation of the mold release rate of sodium silicate sands. Finally, after five water blooms ,the film removal rate of the used sands reached 90.26%.

4. Conclusions

During the incubation of diatoms, the sodium silicate used sands biological regeneration control system realized temperature control, diatom collection and real-time upload of temperature, illuminance, pH and water level data, and remote observation of generator monitoring data using the Yeelink platform, which met the experimental requirements.

1) After 40 days of culture, the sodium silicate-based biological regeneration control system using sand experienced five algal blooms, suggesting that diatoms were susceptible to algal blooms under temperature control conditions.
2) The rapid growth of diatoms led to a substantial consumption of soluble silicate in the old sand, resulting in a significant decrease in the pH value of the sand from 10.2 to 8.2.
3) Ultimately, the removal rate of the film on the used sands reached 90.26%.

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