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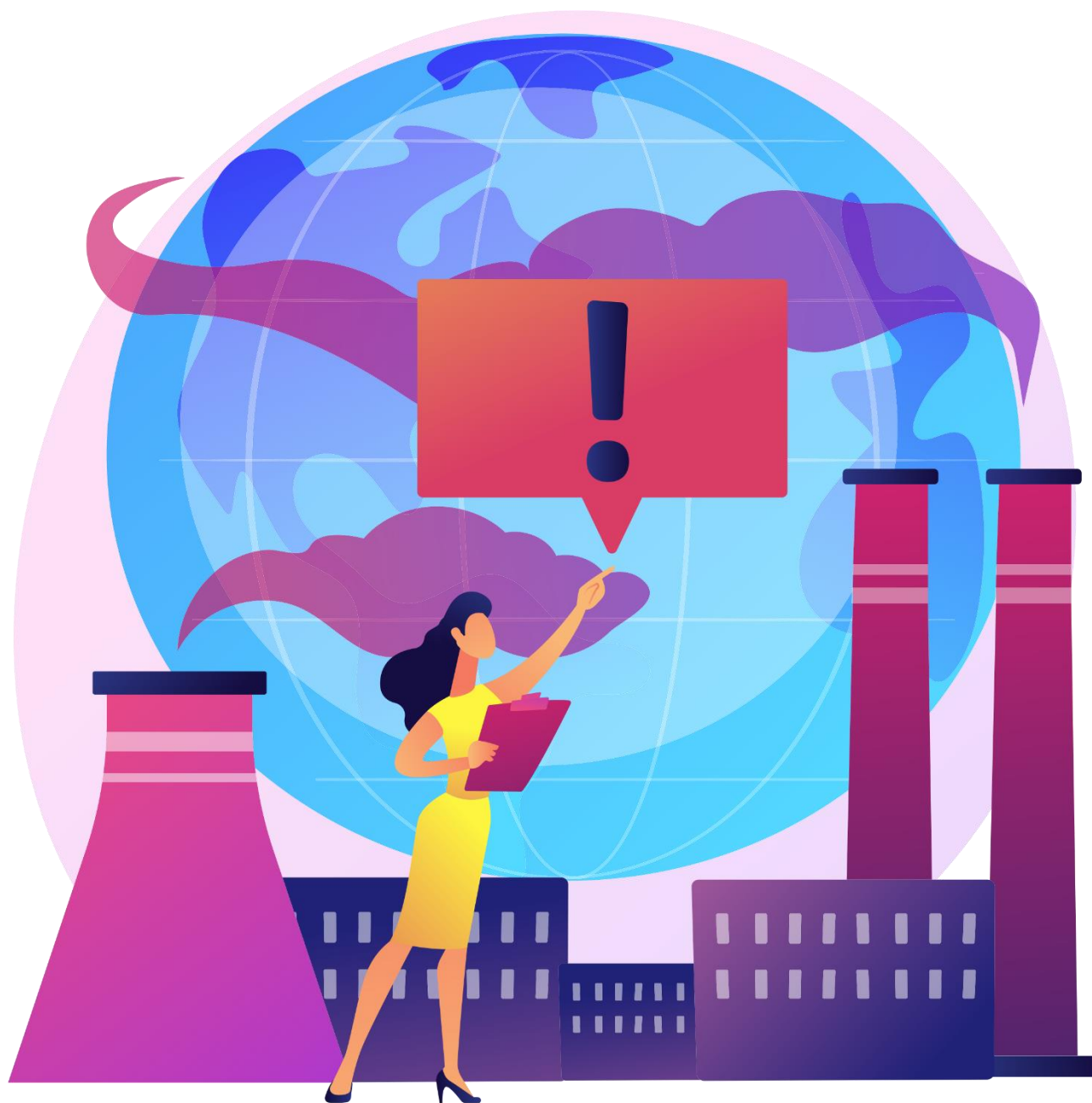
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## THE EFFECTIVENESS OF UPFLOW SLUDGE BLANKET FILTRATION (USBF) TECHNOLOGY FOR DOMESTIC WASTEWATER TREATMENT IN HANOI, VIETNAM

### Abstract

In this study, Upflow Sludge Blanket Filtration (USBF) technology was applied for domestic wastewater treatment in Hanoi, Vietnam. The system was continuously operated for 31 days with HRT 10 h. Before operating the system, the aerobic and anaerobic activated sludge was prepared using the real domestic wastewater environment under laboratory conditions. The characteristics of the system's inlet, outlet wastewater and activated sludge were analyzed and calculated using standard methods. During operation, the MLSS content in the anaerobic and aerobic compartments reached in the range of 5152 – 3741 mg/L and 4165 - 2847 mg/L, respectively. The lowest sludge volume index (SVI) in anoxic compartment found only 49 mL/g. The TSS, COD,  $\text{NH}_4^+\text{-N}$  removal efficiencies reached: 87 - 93%; 82.3% - 94.3 %; 87.07 - 91.35%, correspondance to the outlet values ranged 11.3 - 18.2 mg/L; 12.87 – 28.85  $\text{mgO}_2\text{/L}$ ; 5.15 - 8.45 mg/L, respectively. They all are much lower than National technical regulation on surface water quality of Vietnam QCVN 08:2015-BTNMT in particular  $\text{PO}_4^{3-}\text{-P}$  was less than 1.44 mg/L. The USBF system has a fairly compact size, higher treatment efficiency that is an appropriate solution for domestic wastewater treatment in household scale. Especially, where limited space available like Hanoi and other large urban areas in Vietnam.

### Key words:

domestic wastewater, USBF, water pollution.

### 1. Introduction

Domestic wastewater often contains high content of organics ( $\text{BOD}_5$ , COD), suspended solid (TSS), nutrients ( $\text{NH}_4^+\text{-N}$ ,  $\text{PO}_4^{3-}\text{-P}$ ) and bacteria. In Vietnam, domestic wastewater is often discharged directly into the environment, causing serious impacts on the environment.

Biotechnology has been known and used for the treatment of wastewater widely because it is simple, environmental friendly and low costs. The removal efficiency depends mainly on the type of treatment system, the content of oxygen supplied to the system, the temperature, the content of bacteria as well as the retention time of the system [1-3]. In particular, the biological treatment methods today are being focused because it is relatively simple, environmentally friendly, low operating costs and relatively high treatment efficiency [4, 5].

The basic activated sludge combined with an anoxic process and suspended sludge settling in a biological treatment plant has been enhanced by Bio-USBF then required less space and low cost. In the USBF system, wastewater moves from the bottom of the settling tank through a specifically constructed partition system where the hydraulic flocculation process occurs after being disturbed in this compartment, which has a trapezoidal form. The trapezoidal clarifier maintains a constant flow rate from bottom to top of the sump, allowing for a progressive decrease in velocity gradient (see Fig. 1) [6].

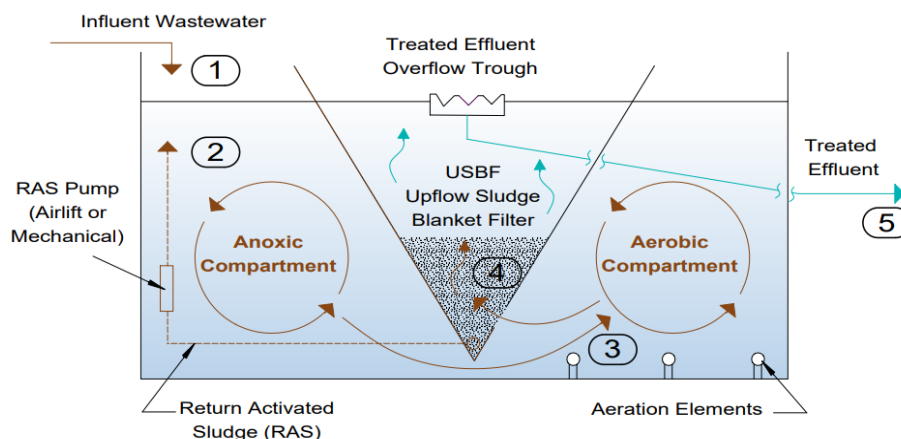


Figure 1 – Diagram of USBF technology (Mesdaghinia et al. 2010)

The tank is designed to remove organics (COD, BOD), and nutrient removal (N and P). All biological treatment and sludge separation processes are provided within the compact integrated biological reactor (IBR). The IBR contains three consecutive biological zones: (i) denitrification zone or anoxic zone; (ii) nitrification zone or aeration zone and (iii) anaerobic zone or separation zone.

Anaerobic and denitrification zones are mixed by mechanical mixers, in the nitrification zone is a fine-bubble aeration system with very high oxygen transfer efficiency providing the oxygen delivery and mixing. The pressure air for aeration is provided by blowers. The USBF separator is build-in in nitrification zone and provides the outflow of treated water. The separated sludge from USBF separator together with nitrates from nitrification zone is recirculated into the denitrification zone, and the mixed liquor from the end of denitrification zone is recirculated to the anaerobic zone. The wastewater inflows into anaerobic zone where it meets with activated sludge recirculated from the denitrification zone. The phosphorus accumulating organisms in activated sludge take in anaerobic conditions some substances from wastewater and release some accumulated phosphorus.

The mixed liquor from anaerobic zone then flows into denitrification zone, where facultative aerobic organisms in activated sludge are taking the oxygen from recirculated nitrates for oxidation and consumption of some substances from wastewater. By this process, nitrates are converted to gaseous nitrogen, which is released to air, and it thus reduces the concentration of total nitrogen in water. The mixed liquor from denitrification zone then flows to nitrification zone, where proceeds the oxidation and consumption of remaining organic substances from wastewater and ammonium is oxidized by nitrification bacteria to nitrates, which are then recirculated to denitrification as described above. The phosphorus accumulating organisms there due to proceeding phosphorus release take in presence of oxygen surplus of phosphorus and convert it to deposited polyphosphates, which results in biological dephosphorization.

USBF technology is a technology that has not been widely applied in Vietnam, the system is compact in size, easy to install, convenient, with high processing efficiency, suitable for crowded urban areas where there limited area.

## 2. Materials and Methods

### 2.1. Chemicals

All chemicals used including  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{HgCl}_2$ , KI, NaOH,  $\text{KNaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$ ,  $\text{H}_2\text{SO}_4$ ,  $\text{NH}_4\text{Cl}$ ,  $\text{KNO}_3$ ,  $\text{NaNO}_2$ ,  $\text{CH}_3\text{COOH}$ , NaOH, Phenol,  $\alpha$  – naphthylamin, EDTA are PA class manufactured by Merck, Germany. For COD determination, used HACH rapid reagent (USA).

### 2.2. Preparation of microbial culture

*Aerobic microbial enrichment culture:* Seed aerobic microorganism were obtained from biological





The system is made of stainless steel, L:W:H = 60:30:40 cm with a capacity  $Q = 140$  L/d. The system includes 3 compartments: Anoxic (HRT of 2.2h), aerobic (HRT of 6h) and USBF (HRT of 1.8h). Two (2) stirrers with blades of 8 cm long, and 1.5 cm wide, 60 rpm are installed in the anaerobic and aerobic compartments. An aeration system with an air distribution rig that is 3 silicon rods, each 20 cm long, the distance between the bars is 10 cm, is installed and fixed at the bottom of the aerobic compartment. Oxygen from air compressor is aerated at a rate of  $13 \text{ m}^3/\text{h}$ .

The domestic wastewater is continuously pumped into the anaerobic compartment with a flow rate,  $Q = 5.9$  L/h. Wastewater, after passing through the anaerobic compartment, continues passes the aerobic before goes into the USBF compartment, then through the serrated trough to collect water on the surface of the compartment. Treated wastewater outlet then is taken out by a one-way valve and stored in a plastic tank.

During operation, the amount of sludge in the USBF compartment is automatically returned to the anoxic chamber by the sludge circulation pump every 2 hours, and the sludge circulation pump once in 15 minutes.

The system was operated continuously for 1 month during August and September, 2022 with a total HRT of 10 hours for the whole system.

### 2.5. Sampling and analytical methods

During the microbial culture enrichment period, samples were taken daily to analyse the MLSS contents and SVI values in both anaerobic and aerobic compartments. During domestic wastewater treatment stages, samples are taken at the input and output of the system to evaluate the treatment efficiency with some key parameters: TSS, COD,  $\text{BOD}_5$ ,  $\text{PO}_4^{3-}\text{-P}$  and  $\text{NH}_4^+\text{-N}$ . Samples were taken daily in anaerobic and aerobic compartments at a depth of 20 cm to determine MLSS and SVI values to assess the level of microbial activity in the system. The TSS, COD,  $\text{BOD}_5$ ,  $\text{PO}_4^{3-}\text{-P}$  and  $\text{NH}_4^+\text{-N}$  were analyzed according to the standard methods.

## 3. Results and Discussion

### 3.1. Bacterial growth in the adaptive microbial culture stage

After being isolated, cultures and enriched aerobic and anaerobic microorganisms are diluted and added into aerobic and anaerobic compartments to be gradually adapted in the real domestic wastewater environment with different pollutant contents at 3 phases (see figure 3).

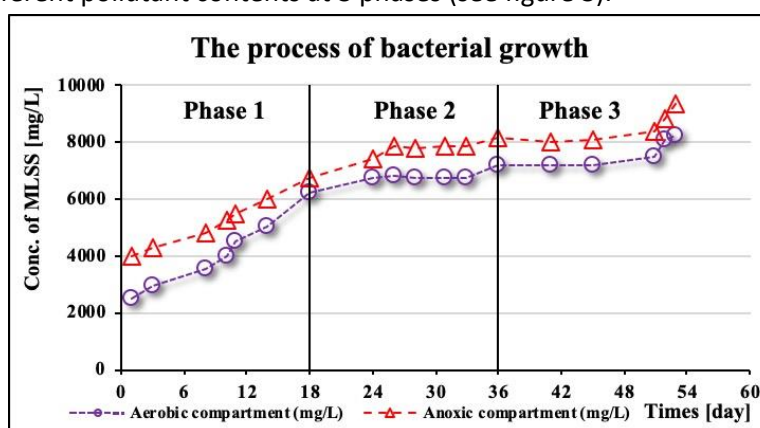


Figure 3 – Bacterial growth (MLSS values) in 3 phases

As can be seen, in the first phase, the MLSS value increases steadily with time that showed the adaptation and enrichment process of microbial culture. During this period, MLSS values increased from 2500 to 6210 and from 4000 to 6740 mg/L in aerobic and anoxic compartments, respectively. In the 2<sup>nd</sup> phase, the

MLSS values found relatively stable, in the range of 6790 - 7210 and 7420 - 8140 mg/L in aerobic and anoxic compartments. In the 3<sup>rd</sup> phase, the microbial density in both compartments continued to be stable although slightly increased compared to phase 2. The results showed that the increase in microbial culture of the acclimatization phase meets the processing requirements in the next step.

### 3.2. Adaptive microbial culture in the USBF system

In biological systems for domestic wastewater treatment, the efficiency of pollutants removal are dependent on the microbial culture. The MLSS content in the aerobic and anaerobic compartments of the USBF system during domestic wastewater treatment is shown in figure 4.

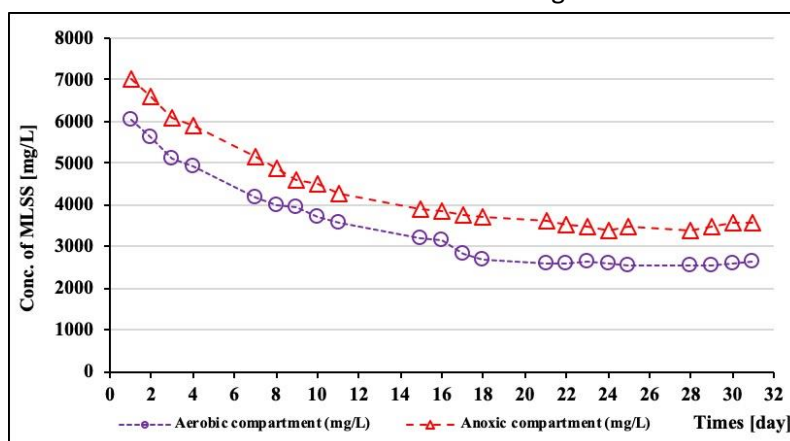


Figure 4 – Variation of MLSS content during domestic wastewater treatment in the USBF system

During the operation of the USBF system, the MLSS contents observed in both anaerobic and aerobic compartments initially tended to decrease. After 17 days, the observed MLSS contents of both compartments tended to be stable. Where in the first 7 days of operation, the MLSS content of both compartments significantly decreased from 7030 to 5152 and from 6020 to 4165 mg/L for the anaerobic and aerobic compartments, respectively. The reason probably is in the first operation week, the HRT was shortened by 2.4 times compared to the phase 3 of culture enrichment and acclimation, HRT 10 and 24 h. At the relative stable pH, temperature, nutrients, the growth rate of microorganisms is similar [6]. When the water flow rate increases, dilute the microorganisms, thereby the MLSS value decreased very quickly in the early phase [8]. During the system operation period, from the 8<sup>th</sup> to the 17<sup>th</sup> day, the density of microorganisms continuously and steadily decreased, however the decrease rate was slower than that of the initial period. The MLSS contents decreased from 4898 to 3741 and from 4003 to 2847 mg/L, respectively in the anaerobic and aerobic compartments. During the system operation period from the 18<sup>th</sup> to the 31<sup>st</sup> day, the MLSS contents kept stable ranging 3400-3700 and 2500 - 2700 mg/L in the anaerobic and aerobic compartments. These values of MLSS found suitable for removing pollutants in the system [9].

The content of microorganisms in both anaerobic and aerobic compartments obtained quite consistent, partly because they are cultured and well adapted to the real domestic wastewater. On the other hand, because of activated sludge circulation that was pumped from the USBF to the anoxic compartment every 2 hours for 15 minutes, thereby supplementing the microorganism deficiency during the treatment process.

### 3.3. TSS removal efficiency

The TSS removal efficiency is evaluated according to the operating time of the UASF system shown in

Figure 5.

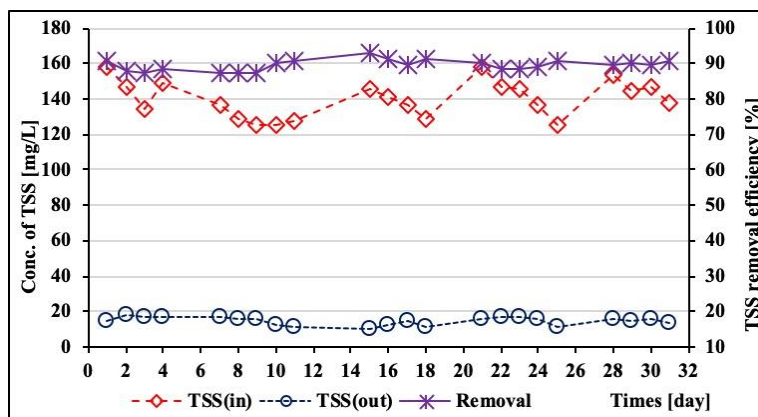


Figure 5 – TSS removal efficiency of USBF system in domestic wastewater treatment

Fig. 5 showed with the input TSS content of 125-158 mg/L, significant decrease of output TSS was found that remains of 11.3-18.2 mg/L corresponding to the removal efficiency of 87 to 93%. The high TSS removal efficiency of the USBF system probably due to the adsorption of suspended solids on the biological flocs, also the SVI in the aerobic compartment of the system are relatively low (Figure 6), therefore suspended solids were well settled down [10]. In addition, the decomposition of organic compounds by aerobic microorganisms as well as heterotrophic denitrifying bacteria contributes significantly to the removal of suspended solids [11].

The obtained results found quite similar to other studies [12] and the TSS values after going through the system are much lower than that National technical regulation on surface water quality of Vietnam 08/2015 BTNMT.

### 3.4. Evolution of SVI

One of some import parameters that have to control during wastewater bio-treatment process is SVI. The SVI can be determined with the 30-minute settle activated sludge (MLSS) test result to come up with a number (or index) that describes the ability of the sludge to settle and compact (Eq (1)). SVI gives a more accurate picture of the sludge settling characteristics than settle ability [13, 14].

$$SVI = \frac{V_{30} \times 1000}{TSS} \text{ (mL/g)} \quad (1)$$

Where:  $V_{30}$ – Sludge volume in 30 minutes (mL/L)

The results of SVI calculation in the aerobic compartment of the USBF system during the operation of domestic wastewater treatment are shown in figure 4 below:

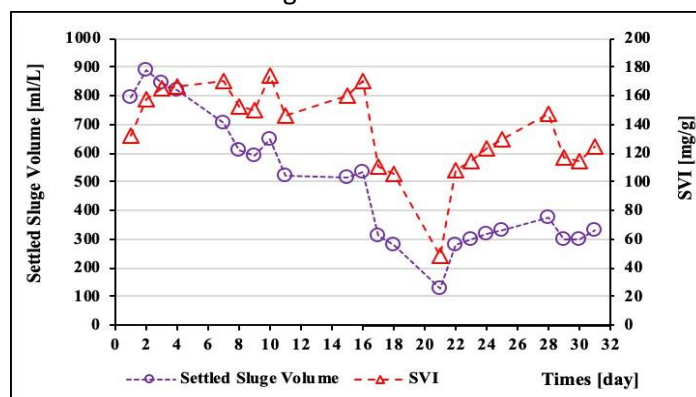


Figure 6 – Variation of SVI values in the aerobic compartment of the USBF system

The observed SVI showed that during the first 17 operation days, the SVIs were mainly greater than 150 mL/g, which could be explained as due to bulking or the proliferation of filamentous bacteria in aerobic bioreactors. On the other hands, on day 21, it is observed the SVI of the aerobic bioreactor decreased to 49 mL/g. This value is less than 50 mL/g, indicating that the bio-sludge in the aerobic compartment has good settling properties (insufficiently concentrated flocs are affected by aeration) [10, 15]. The SVI variation in USBF system can be biased due to filtration errors and problems with the growth of bacteriophages yarns.

The SVI shows that the sludge separation ability of the USBF system in the domestic wastewater treatment is very good, which helps to increase the efficiency of TSS removal.

### 3.5. COD removal efficiency

In the USBF system, the sequence of wastewater moving from the anaerobic compartment to the last aerobic compartment through USBF has brought relative high treatment efficiency (see Figure 7).

As showed in Figure 7, COD of the input domestic wastewater kept unstable, ranged from 100 to 230 mgO<sub>2</sub>/L. At the HRT of 10 h, the COD values of outputs reached about 13-29 mgO<sub>2</sub>/L and complied with the acceptable standard. Although the input COD values significantly fluctuated, the output COD found quite stable with very high organic removal rates ranging 82.3-94.3 %. In addition, organic decomposition were performed in all three anoxic, aerobic and USBF compartments as reported in the study of Boutchich et al [10]. This is occurred by heterotrophic or carbonate bacteria in the aerobic compartment of USBF system. These bacteria absorb and thus remove organic compounds from the liquid mixture and use them for respiration or for the growth of new biomass [16]. However, a special biological process in the aerobic compartment is capable of breaking down organic compounds into carbon dioxide (CO<sub>2</sub>), water (H<sub>2</sub>O) and other inorganic compounds [16].

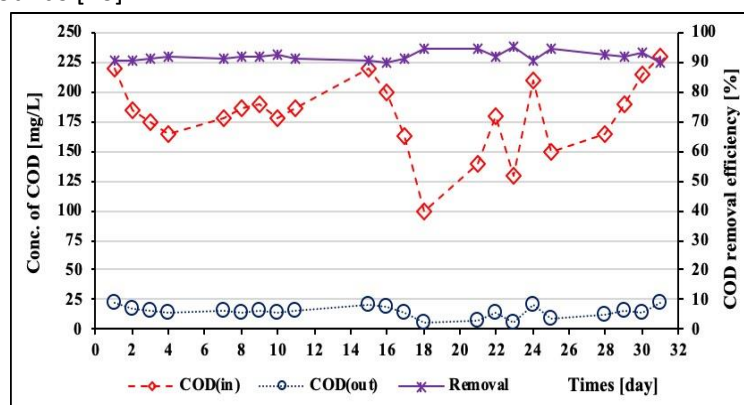


Figure 7 – COD values in outputs and removal efficiency of the USBF system

In the anaerobic and USBF compartments, the removal efficiency of organic compounds is not as good as in the aerobic compartment [17]. The residual organics (COD in the outlets) can be explained by the presence of a fraction of non-biodegradable organic matter in the treated wastewater [12].

At the HRT of 10 h for the whole system, the circulating pump of the activated sludge from the USBF compartment to the anaerobic compartment makes the MLSS content higher than that of the aerobic compartment, simultaneously the MLSS contents found higher and stable in both anaerobic and aerotoc compartments after 17 day operation (figure 7). Thereby making the organic removal efficiency quite stable and very high.

### 3.6. Nutrients (NH<sub>4</sub><sup>+</sup>-N and PO<sub>4</sub><sup>3-</sup>-P) removal efficiency

The efficiency removal of NH<sub>4</sub><sup>+</sup>-N and PO<sub>4</sub><sup>3-</sup>-P in domestic wastewater by the USBF system is shown in figure 8.

The results showed that the UASF system has high efficiency in ammonium treatment, reaching 87.07 to 91.35 %. Output  $\text{NH}_4^+\text{-N}$  values meet the Vietnamese technical regulation for domestic wastewater.

The removal of  $\text{NH}_4^+$  is mainly through nitrification and denitrification in the anaerobic and aerobic compartments. During these processes, *Nitrosomonas* and *Nitrobacter* bacteria oxidize  $\text{NH}_3/\text{NH}_4^+$  to nitrate in the aerobic zone. The nitrate is recycled back to the anoxic region and is continuously reduced. The input organic compounds are considered as electron and energy sources to reduce nitrate to  $\text{N}_2$  molecules [18]. The combination of two anoxic and aerobic compartments in the process of nitrification and denitrification provides high performance, stability and cost savings for the system [19]. The nitrogen removal efficiency of the USBF system is affected by various parameters, especially the microbial community of the biomass [18]. During operation system the concentration of MLSS achieved about 3400-3700 and 2500-2700 mg/L in the anaerobic and aerobic compartments, that creating a seeding effect, thereby enhanced the cotton capture ability of the nitrate-rich biofilm [20] and increased further strengthen the nitrification process [21]. In addition, in the USBF compartment, the activated sludge contributes a significant part to the removal of nitrogen compounds through the denitrification process.

The removal of phosphorus compounds in the USBF system is mainly through the uptake pathway and phosphorus accumulation by organisms [22]. In addition, it depends on the operating conditions, including the prerequisites for metabolism, such as carbon, glycogen and electron acceptor requirements, organic load, nutrients and the C:N:P ratio [22, 23].

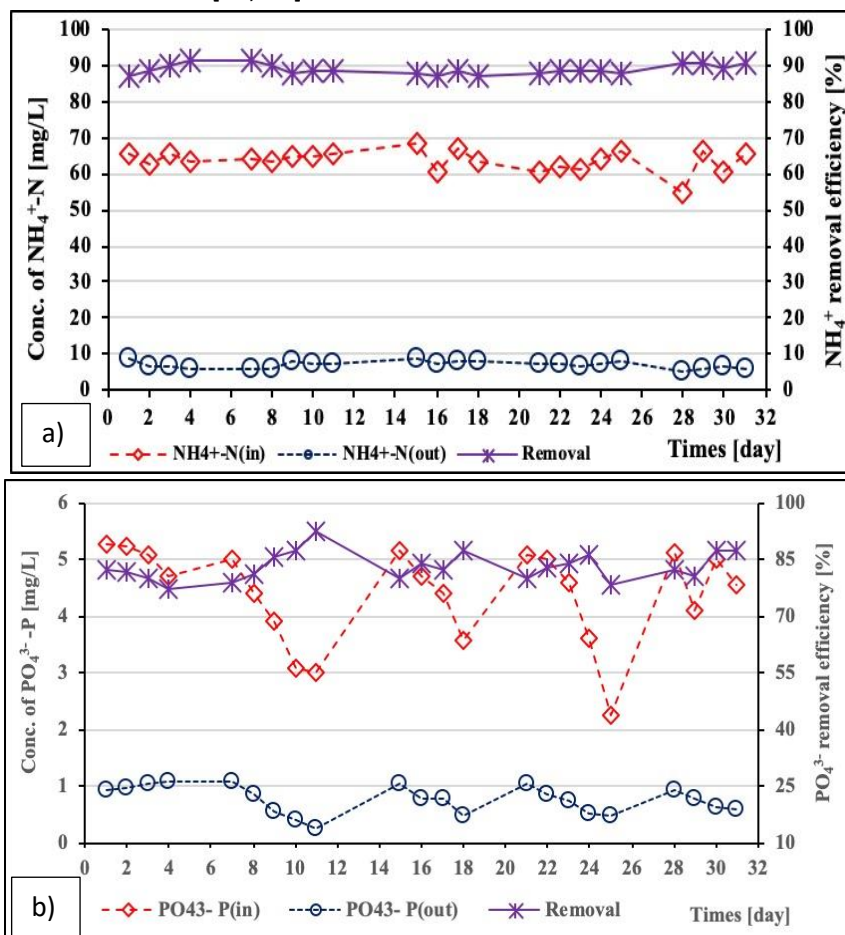


Figure 8 – Hiệu quả loại bỏ  $\text{NH}_4^+\text{-N}$  (a) and  $\text{PO}_4^{3-}\text{-P}$  (b) của hệ thống USBF trong quá trình xử lý nước thải sinh hoạt

As showed in Figure 8, the input  $\text{PO}_4^{3-}\text{-P}$  ranged from 7.53 to 9.43 mg/L, after treatment, the  $\text{PO}_4^{3-}\text{-P}$  concentration in output decreased significantly to 1.44 mg/L and kept stable corresponding to the removal efficiency of over 82.77%. The results of this study found in accordance with the results of other studies [6, 23].

In the USBF system, the microorganism strain *Acinetobacter SP.* participates in the process of phosphorization, the organic compounds present in the wastewater will be converted into phosphorus-free or phosphorus-containing compounds but then easily decomposed with aerobic microorganisms in the next process. The ability of facultative anaerobic bacteria *Acinetobacter* to take phosphorus is greatly increased when it circulates under different oxygen conditions [24]. In the anaerobic compartment, the facultative anaerobic bacteria *Acinetobacter SP.* often accumulate more complex carbon sources, such as amino acids and proteins, which they store as an unknown substance [25]. Dissolved organic compounds are fermented in the aerobic and anaerobic compartments, the products that make up the special composition of microorganisms, making them capable of storing phosphorus. After homogenization, phosphorus will be discharged from the system in the USBF compartment [22].

Besides the facultative anaerobic bacteria *Acinetobacter sp.*, other organisms such as *Pseudomonas sp.*, *Paracoccus sp.* and some *Enterobacter sp.* also participate in phosphorus accumulation [26, 27]. Some microorganisms may involve in both accumulate phosphorus and perform the denitrification process under alternate anaerobic-aerobic conditions [28]. Phosphorus-reducing organisms use nitrate as the sole terminal electron acceptor instead of oxygen to oxidize PHA under anoxic conditions [29].

The high phosphorus removal efficiency obtained in the USBF system may be because of the stable MLSS content in the anaerobic and aerobic compartments, the adequate microbial culture even the input C:N:P ratio is not stable.

#### 4. Conclusions

The application of USBF technology to treat real domestic wastewater taken in the Hoang Quoc Viet bridge area shows that this technology brings very high treatment efficiency. Although the input and output pollutants' content were not stable, the treatment efficiency found very high,. The pollutants removal efficiency is very high, reached 89.5, 89.4, 89.09 and 87.11% for TSS, COD, % for  $\text{NH}_4^+\text{-N}$  and  $\text{PO}_4^{3-}\text{-P}$ , respectively and meet with National technical regulation on surface water quality of Vietnam. With a compact size design, USBF technology was found suitable for application to households scale in large urban areas in Vietnam.

The USBF technology shows application prospects in term of environmental and economic effects, contributing to reducing the pressure on receiving waste streams of water bodies and surface water environment.

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