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# Selection of suitable filter materials for subsurface flow constructed wetland systems for wastewater treatment in rice noodle handicraft village

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**Abstract.** This study aims to select suitable filter materials for Subsurface Flow Constructed Wetlands (SSF CW) to treat wastewater from rice noodle handicraft villages, based on a combination of new materials (plastic waste and rice husk) and traditional substrates (limestone, gravel, and sand). Four SSF CW models using different filter materials were tested during three months, including CW1 (limestone, gravel, and sand), CW2 (sand, plastic waste, and gravel), CW3 (sand + rice husk, limestone, and gravel), and CW4 (sand + rice husk, plastic waste, and gravel). The results indicated that CW3 and CW4 systems were more effective to plant growth. Replacing limestone with plastic waste did not show a significant difference in treatment efficiency ($p > 0.05$), however the addition of rice husk decreased the efficiency of organic matter treatment while increasing nutrient treatment efficiency ($p < 0.05$). The highest treatment efficiencies for TSS and COD were observed in CW1, at 83.89 ± 1.38 % and 79.56 ± 1.36 %, respectively. Meanwhile, the highest treatment efficiencies for TN, $NH_4^+$, and TP were recorded in CW4, at 80.14 ± 2.76 %, 88.39 ± 1.62 %, and 82.22 ± 2.51 %, respectively. The effluent water from all four SSF CW models met the Vietnamese standard for wastewater quality (QCVN 40:2011/BTNMT, column B). This study demonstrates the potential of using a combination of plastic waste, rice husk, and sand as suitable filter substrates for SSF CW in treating wastewater from rice noodle handicraft villages.

*Keywords:* Subsurface flow constructed wetland, rice noodle handicraft village wastewater, plastic waste, rice husks.

*Classification numbers*: 3.3.1, 3.4.2, 3.7.2

## 1. INTRODUCTION

Subsurface Flow Constructed Wetland (SSF CW) technology offers a cost-effective and environmentally friendly solution with high treatment efficiencies for organic substances and nutrients in wastewater [1, 2]. However, the practical application of these systems may be limited by several adverse conditions such as a low carbon-to-nitrogen (C/N) ratio at the input, high pollutant loads, and fluctuating hydraulic loads [3, 4]. Moreover, clogging is the most common issue observed in SSF CWs if the filter material is not properly designed [5]. Numerous studies indicated that the choice of filter material could enhance pollutant removal efficiency and increase the lifespan of the wetlands [5 - 7]. Common materials used in wetland design include gravel (32 %), sand (23 %), and limestone (11 %) [8]. Gravel helps retain large particulate matter and provides a habitat for microorganisms, facilitating the oxidation and degradation of pollutants [9, 10]. Sand, with its smaller particle size, filters finer particulate matter and enhances the contact between water and microorganisms, improving the filtration efficiency of the system. Limestone, being alkaline, adjusts the pH of wastewater, and removes heavy metals and phosphates through adsorption and precipitation mechanisms [10, 11]. However, these filter materials are not always the preferred choice, depending on the characteristics of the wastewater, performance, or cost. Consequently, some wetland systems are designed similarly to traditionally constructed wetlands but vary in the composition of filter materials. Supplementary or alternative materials facilitate biofilm formation and plant growth, as well as enhance physicochemical adsorption processes to maximize pollutant removal efficiency [12]. For example, using plastic waste, which is 8.5 times less dense than gravel, has several advantages including lower cost, easier installation, reduced damage to the base layer, extended lifespan [13], reduced clogging [14], and contributes to the sustainability of the environmental treatment process [15]. However, inorganic materials may not be conducive to initial plant growth and may require regular fertilization. This can affect treatment performance, especially for nutrients like nitrogen and phosphorus, and may lead to secondary pollution from fertilizers. Organic materials have advantages over inorganic ones because they provide a beneficial amount of humus for the growth of plants and microorganisms, and increase the C/N ratio in CWs [6]. Some common organic materials used in CWs include coconut fiber, bagasse, and rice husk [16-21], of which, rice husk has shown great potential due to its availability, low cost, and effectiveness in wastewater treatment [19 - 21]. Utilizing available and inexpensive materials such as rice husk and plastic waste can reduce the cost of technology and may be a preferred choice, after their treatment efficiency being considered. Previous studies have not compared the equivalent roles of plastic waste and rice husk with common materials (limestone, gravel, and sand) in the design of SSF CW for treating a specific wastewater source, especially for wastewater from rice noodle handicraft village, where there is no publication on this subject, yet.

In Vietnam, the issue of environmental pollution treatment in rice noodle handicraft villages is challenging due to the dispersal source and high concentrations of pollutants. The greatest challenge for traditional village wastewater is not only technological solutions but also the cost of treatment [22]. Recent scientific advancements have introduced many advanced technologies, where low-cost natural wastewater treatment methods are prioritized. Therefore, SSF CW technology shows great potential for application in rice noodle handicraft villages. Additionally, plastic waste is a big environmental issue in Vietnam, and reusing plastic waste as a substrate in CWs may offer dual environmental benefits. Rice husk is also widely available and inexpensive. The development of substrates with lower commercial value, reusable materials, and alternative materials holds significant potential, especially in developing countries with limited budgets for environmental protection activities. This study aims to develop an SSF

CW with an appropriate filter setup to treat wastewater from rice noodle handicraft villages. The filter is based on a combination of organic and inorganic materials to achieve better pollutant removal capabilities and a more sustainable lifecycle. To better understand the effectiveness of the new filters, their treatment results will be compared with traditional filters. This study also presents a comparison of the potential applications of filters based on cost and environmental benefits.

## 2. MATERIALS AND METHODS

### 2.1. Materials

The wastewater sample was collected from the outlet after biogas treatment at Da Mai rice noodle handicraft village, Da Mai ward, Bac Giang city, Bac Giang province, Vietnam. This is a traditional craft village with 220 households engaged in rice noodle handicraft. The wastewater from production is collected together with domestic wastewater and treated using a biogas system. However, the post-biogas wastewater still contains high levels of Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Total Nitrogen (TN), Ammonia ($NH_4^+$), and Total Phosphorus (TP) (Table 1), exceeding the permissible standards according to QCVN 40:2011/BTNMT, column B.

Plastic waste includes polyethylene (PE) straws, with a density of 0.91-0.94 g/cm³, collected from trash at cafes in Hanoi, Vietnam. The polyethylene (PE) straws are then cut into segments of 4-5 cm in length and folded in half, which were cleaned before use. Rice husk was anaerobically hydrolyzed at room temperature for 1 month, supplemented with an organic degrading microbial preparation (DW 97), produced by Vietnam Biochemical Technology Joint Stock Company, available on the market, which includes *Bacillus* spp. strains and other microorganisms. This process, lasting one month, was aimed at reducing the organic load released during use and as an addition of organic fertilizer to the substrate, followed by washing and drying. Other materials used included limestone (10x20mm), gravel (30x40mm), and sand, all supplied by building material shops in Vietnam, and were washed clean before use in the design of the SSF CW.

*Table 1.* Characteristics of post-biogas wastewater at Da Mai rice noodle handicraft village

| Parameter | Unit | Value | QCVN 40:2011/BTNMT, Column B |
|---|---|---|---|
| pH | - | 6.03±0.02 | 5.5-9 |
| COD | mg/l | 623.43±9.72 | 150 |
| TSS | mg/l | 216.89±2.71 | 100 |
| TN | mg/l | 68.5±3.14 | 40 |
| $NH_4^+$ | mg/l | 33.61±2.5 | 10 |
| TP | mg/l | 14.64±1.38 | 6 |

*Note: QCVN 40:2011/BTNMT, Column B refers to the national technical regulation on industrial wastewater.*

### 2.2. Experimental Design

The constructed wetland systems were placed outdoors, under a shelter, near the outlet of the biogas tank at Da Mai craft village. The environmental conditions included temperatures from 25 - 35 °C, humidity from 85 – 92 %, and average sunlight hours from 12.35 to 13.16 hours per day. Four wetland models were designed with identical dimensions: 2 meters long × 0.5 meters wide × 1 meter high. Different layers of filter materials were vertically arranged (Figure 1; Table 2). Gravel (size 30 × 40 mm), limestone (size 10 × 20 mm), hydrolyzed rice husk, plastic waste, and sand were used as filtering materials (Table 2). *Cyperus alternifolius* was planted across all four models for two months to allow stable growth before initiating the experiments with wastewater. Each model was planted with two rows of trees (Figure 2). Before starting the experiment, *C. alternifolius* had an initial height of 15 cm and a density of 54 plants/m$^2$. The experiment was conducted over three months, with wastewater continuously fed into the system using a dosing pump at a flow rate of 100 liters per day, evenly distributed over the filter area through perforated PVC pipes. A drainage channel at the bottom of each experiment collected the output water samples. Sampling and analysis of wastewater quality were conducted every five days at the inlet and outlet of each model for measuring parameters such as pH, COD, TSS, TN, $NH_4^+$, and TP. At the end of the experiment, plant growth was assessed by measuring dry biomass weight, height, and the number of new shoots. Each experiment was replicated three times.

*Table 2.* Description of filter design in the four constructed wetland models

| Experiment | CW1 | | | CW2 | | | CW3 | | | CW4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Material | Sand | Limestone | Gravel | Sand | Plastic waste | Gravel | Sand + rice husk* | Limestone | Gravel | Sand + rice husk* | Plastic waste | Gravel |
| Height of the filter model (cm) | 15 | 25 | 40 | 15 | 25 | 40 | 15 | 25 | 40 | 15 | 25 | 40 |

*The mixture of sand and rice husk were thoroughly mixed, with rice husk comprising 20%.

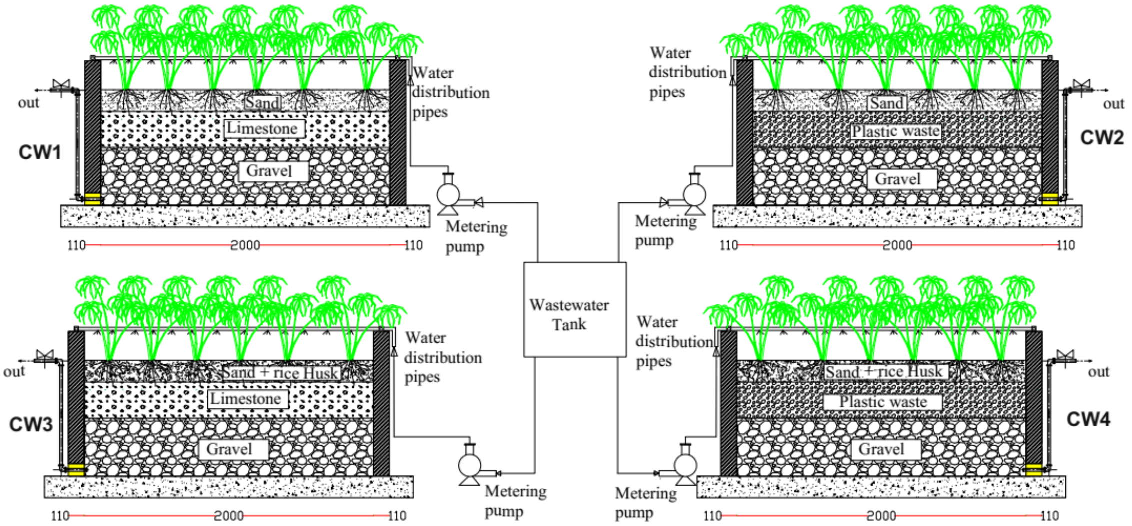

*Figure 1.* Four SSF CW models with different filter materials.

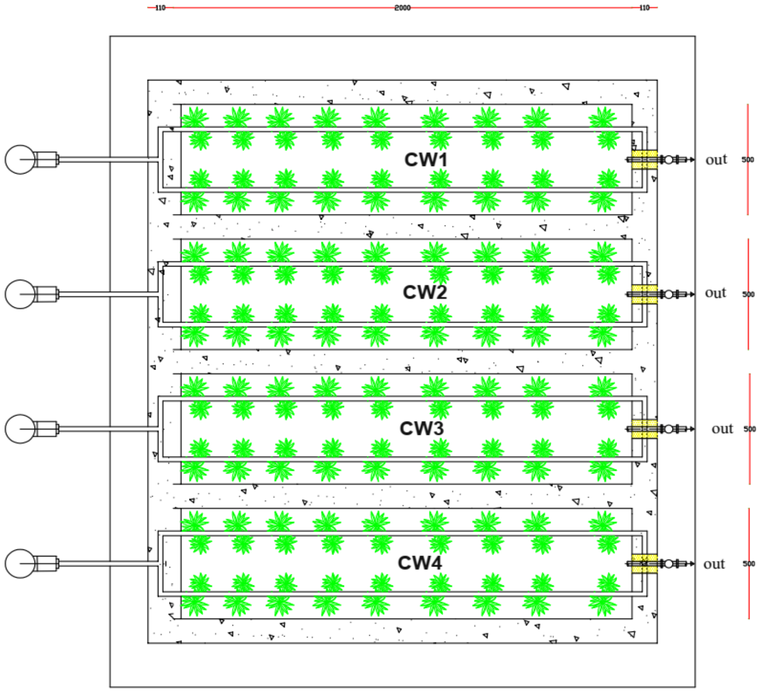

*Figure 2.* Layout of four SSF CW models.

## 2.3. Water Quality Analysis

To determine water quality, the following parameters in the wastewater were analyzed using standard methods for water and wastewater testing in Vietnam. pH was measured according to TCVN 6492:2011, COD was determined by the potassium dichromate colorimetric method (TCVN 6491:1999), and TSS was measured by filtration through a fiberglass filter (TCVN 6625:2000). Total Nitrogen (TN) was measured by the catalytic oxidation method following reduction with Devarda's alloy (TCVN 6638:2000). Ammonia was determined by the distillation and titration method (TCVN 5988:1995). Total Phosphorus (TP) was determined by the spectrophotometric method using ammonium molybdate (TCVN 6202:2008).

## 2.3. Data Analysis

The removal efficiency (%) of the CW is calculated using the following formula:

$$H\ (\%) = (C_{in}-C_{out})/C_{out} \times 100\%\ (1)$$

where H is the removal efficiency (%); $C_{in}$ is the inlet pollutant concentration (mg/l); $C_{out}$ is the outlet pollutant concentration (mg/l).

The removal rate of the CW is calculated as follows:

$$R = (C_{in} - C_{out}) \times Q/S\ (2)$$

where $C_{out}$ is the outlet pollutant concentration ($g.m^{-3}$), $C_{in}$ presents the inlet pollutant concentration ($g.m^{-3}$), R is the removal rate ($g.m^{-2}.d^{-1}$), S is the area of the planted filter bed ($m^2$), and Q presents the water flow rate through the filter bed area per day ($m^3.d^{-1}$).

The number of plant shoots is determined by direct counting on the experimental systems. The number of new shoots (n, plants/m$^2$) is calculated as the number of shoots after the experiment (n, plants/ m$^2$) minus the number of old shoots (54 plants/ m$^2$), using the following formula:

$$N = n - 54 \quad (3)$$

Determine height: 20 plants were randomly collected after the experiment. Then, the height of the plant stem (excluding root length) was measured using a ruler. The average value is taken as the post-experiment height of the plants.

Dry biomass is determined through the following steps: Step 1: Randomly harvest all plants in 5 plots per model (each plot being 400cm$^2$), clean the stems, roots, and leaves, and number the corresponding plots. Step 2: Separately dry the biomass from each plot collected in Step 1 until constant weight at 80°C using a Shel Lab CE5F-2 dryer. Step 3: Determine the dry biomass weight using an analytical balance. Step 4: Calculate the average value of dry biomass weight across the 5 plots. Dry biomass is determined as follows:

$$B = b/0.04 \quad (4)$$

where B is the dry biomass weight (g/m$^2$); b is the average weight of dry biomass across the 5 plots (g); 0.04 is the area of each sampled plot (m$^2$).

### 2.4. Statistical Analysis

Data were statistically processed and preliminarily analyzed using Excel 2016 software. Advanced statistical analysis was conducted using SPSS 20.0 (SPSS Inc, IBM, USA). All data were tested for normal distribution using the Kolmogorov-Smirnov test. A one-way Analysis of Variance (ANOVA) was performed to determine any significant differences between experiments, followed by a Tukey post-hoc test, with $p < 0.05$ indicating statistical significance.

## 3. RESULTS AND DISCUSSION

### 3.1. Plant Growth

Plant growth plays a crucial role in the pollution removal mechanism of CW, especially for nutrients [23]. *Cyperus alternifolius* is commonly used in CWs due to its high pollution absorption capacity, resilience, year-round greenery, and suitability for the Vietnamese climate. In this study, all four SSF CW models were suitable for plant growth. *C. alternifolius* thrived with no plant mortality observed. The traditional materials such as limestone, gravel, and sand were proven suitable for the growth *C. alternifolius*, with new shoot counts of 28 shoots/m$^2$, a height of 67.6 ± 3.8 cm, and a biomass yield of 2536 ± 12 g/m$^2$, consistent with previous studies [24, 25]. In CW2, where plastic replaced limestone, no adverse effects on plant growth were detected; new shoots, height, and biomass were respectively 30 shoots/m$^2$, 67.4 ± 6.6 cm, and 2567 ± 20 g/m$^2$. Differences only occurred with the addition of organic material at CW3 and CW4. There was no significant height variation among the SSF CWs, but the new shoot count and biomass in CW3 and CW4 were higher than in CW1 and CW2 (Table 3). Among the four SSF CW models, CW3 had the highest new shoot count and biomass, respectively at 44 shoots/m$^2$ and 3052 ± 11 g/m$^2$. The purpose of adding organic material was to enhance plant growth. Common substrates (sand and gravel) used in CWs do not provide organic carbon. Organic materials provide a certain amount of organic humus that helps increase the C/N ratio and improve nutrient absorption by plants [6]. Rice husk allows the roots of wetland plant mats to penetrate deeper than gravel, thus providing a higher root density [20]. Previous reports often used *C. alternifolius* planted on a filter material of gravel and sand, achieving a biomass of 2430 - 2590 g/m$^2$ and a density of 77 plants/m$^2$ [25]. This study provides further evidence of the viability of using *C. alternifolius* planted on alternative substrate materials including plastic waste and rice husks in wastewater environments of rice noodle handicraft village. Moreover, in nutrient-poor conditions, rice husk may be a more optimal choice for plant growth compared to conventional inorganic materials.

*Table 3.* Growth indices of *C. alternifolius* in the CW models

| Plant growth | Wetlands | | | |
|---|---|---|---|---|
| | CW1 | CW2 | CW3 | CW4 |
| Shoot/m$^2$ | 28 | 30 | 44 | 40 |
| Height: cm | 67.6 ± 3.8 | 67.4 ± 6.6 | 66.4 ± 5.3 | 65.4 ± 2.8 |
| Biomass: g/m$^2$ | 2536 ± 12 | 2567 ± 20 | 3052 ± 11 | 2994 ± 22 |

## 3.2. Evaluation of Pollution Treatment Efficiency

### *3.3.1. Organic Matter Treatment (COD Removal)*

The initial COD values in the rice noodle production wastewater were 4.15 times higher than the allowable standard (QCVN 40:2011/BTNMT, Column B). After treatment through the SSF CW systems (CW1 – CW4), the COD values significantly decreased and met the QCVN 40:2011/BTNMT, column B standards (Figure 3, Table 4). However, there were differences in treatment efficiency among the SSF CW systems ($p < 0.05$). Specifically, CW1, using traditional materials, had the highest COD removal efficiency at 83.89 ± 1.38 %; CW2, where plastic replaced limestone, had the second highest efficiency at 82.39 ± 1.04 %; CW3 and CW4 had the lowest efficiencies, at 78.89 ± 1.42 % and 78.97 ± 0.89%, respectively. The COD removal efficiency in models CW1 – CW4 was comparable to previous studies, ranging from 77 to 84 % [26, 27].

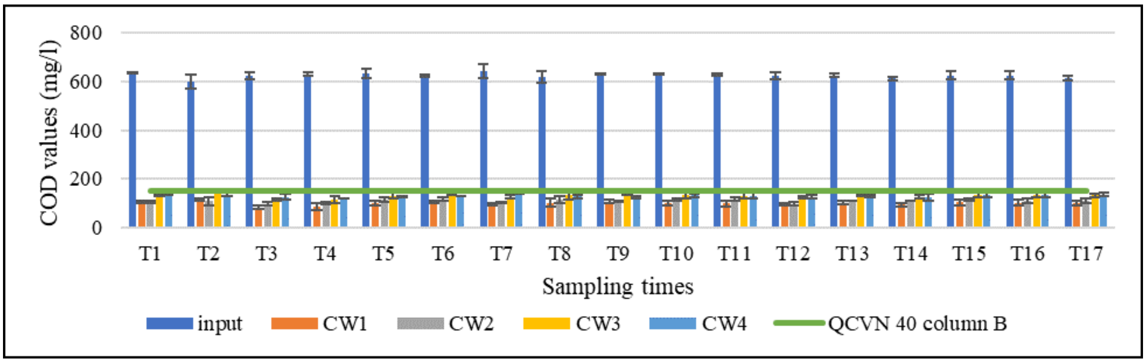

*Figure 3.* COD values in the influent and effluent of four experimental models.

The plastic material, with its large specific surface area, allows microbes to adhere to it, which can enhance the COD removal process [12]. Previous reports have shown COD treatment efficiencies ranging from 71 - 88 % [28], suggesting that plastic can be used to treat COD in SSF

CWs. Meanwhile, the presence of rice husk reduced the COD treatment efficiency in CW3 and CW4. The organic carbon content in rice husk, which constitutes 33.94 % [29], increased the COD value in the wastewater due to organic decomposition. However, K. Sonu et al. reported a COD treatment efficiency of up to 85.29 % in a CW-containing rice husk [21]. In this experiment, only a portion of sand was replaced with rice husk to balance the treatment rate of the CW and the organic load generated from the rice husk. Also, the initial hydrolysis process significantly reduced the organic load. The outlet COD values at CW3 and CW4 were respectively 131.61 ± 7.8 and 131.12 ± 5.35 mg/l, meeting the QCVN 40:2011/BTNMT, column B standards.

### *3.3.2. TSS Treatment*

In this study, the inlet TSS value was 216.899 ± 2.71 mg/l, which is approximately 2 times higher than the QCVN 40:2011/BTNMT, column B standards. The TSS concentrations decreased after treatment by the CW1 – CW4 systems and there were differences between the various substrates ($p < 0.05$). The TSS treatment efficiencies at CW1 and CW2 were 79.56 ± 1.36 % and 78.6 ± 1.35 %, respectively, without a significant difference ($p > 0.05$) but higher compared to CW3 and CW4 ($p < 0.05$). Suspended solids were removed through sedimentation and filtration processes. Plant roots play a role in filtering to slow down the flow rate, improve sedimentation, and reduce turbidity [29, 30], but most of the suspended solids were trapped in the pores of the filter [26]. The organic decomposition process from the rice husk may have increased the TSS levels in the wastewater, leading to the lowest treatment efficiencies at CW3 and CW4, at 73.06 ± 1.16 % and 72.94 ± 1.44 % respectively, which are lower than the previous reports where TSS treatment efficiencies ranged from 81 – 88 % [22, 31]. However, the outlet TSS values always met the permissible standards in all SSF CW systems (Figure 4). Therefore, all four SSF CWs met the requirements for TSS treatment in wastewater from the Da Mai rice noodle handicraft village.

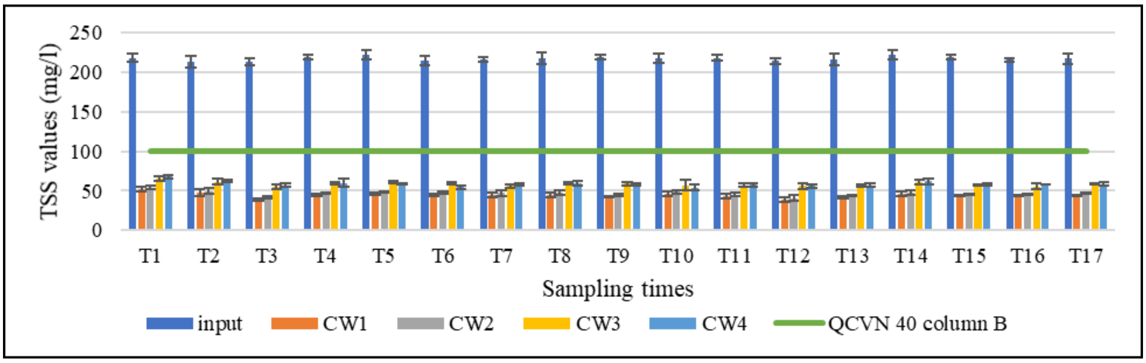

*Figure 4.* TSS values in the inlet and outlet wastewater of the four experimental models.

### *3.3.3. Nutrient Treatment*

Among the four wetland models, there was a significant difference in TN treatment efficiency (Table 4, $p < 0.05$). The TN removal efficiencies in CW3 and CW4 were consistently higher than in CW1 and CW2 ($p < 0.05$). Similarly, the TN removal rates were the highest in CW3 and CW4, at 5.25 ± 0.36 $g.m^{-2}.d^{-1}$ and 6.01 ± 0.55 $g.m^{-2}.d^{-1}$, respectively, followed by CW1 (4.53 ± 0.46 $g.m^{-2}.d^{-1}$) and CW2 (4.18 ± 0.44 $g.m^{-2}.d^{-1}$). Adding rice husk increased the organic content in the filter, and previous reports indicated that a suitable carbon/nitrogen ratio helps enhance nitrogen treatment efficiency in CW systems [3, 32]. The added carbon enhances the denitrification process, thus improving nitrogen treatment efficiency [15]. In this report, the highest TN treatment efficiencies were recorded in CW4 at 80.14 ± 2.76 % and CW3 at 76.71 ± 2.77 %, however the statistical analysis indicated that the lower values were not significantly different ($p > 0.05$). Thus, the difference in substrates between CW3 and CW4 did not affect TN treatment efficiency, allowing for the substitution of limestone with plastic waste in the filter design and vice versa. The sand, plastic waste, and gravel filter had the lowest TN treatment efficiency at 61 ± 4.44 % but was higher than previous reports, where TN treatment efficiency ranged from 34.9 – 52 % [13, 15]. Importantly, the TN values in the wastewater met the standards in all four SSF CW models (Figure 5).

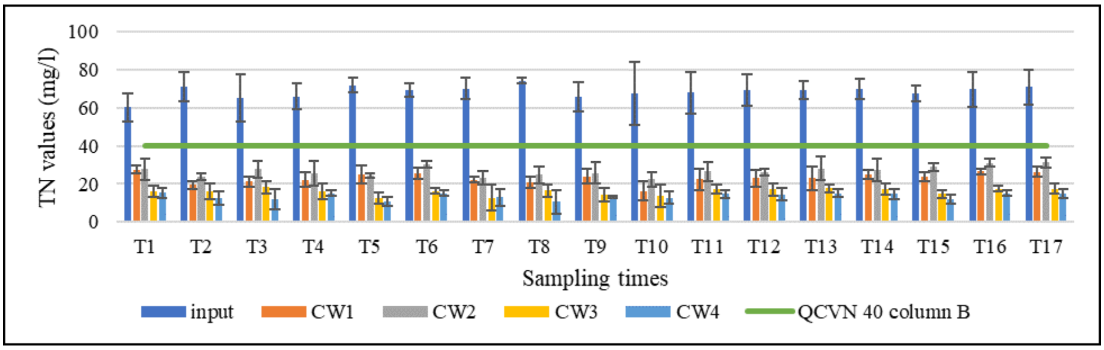

*Figure 5*. TN values in the inlet and outlet wastewater of the four experimental models.

Ammonium ($NH_4^+$), a readily bioavailable form of nitrogen, serves as a nutrient for plants and is directly absorbed by them, simultaneously reducing pollution. The $NH_4^+$ removal efficiencies of the four models ranked as follows: CW3, CW4 > CW1 > CW2 ($p < 0.05$). This is consistent with the plant growth results, where plants in CW3 and CW4 showed the best growth and the highest $NH_4^+$ removal efficiencies, at 87.58 ± 2.08 % and 88.39 ± 1.62 % respectively. CW2 had the lowest $NH_4^+$ removal efficiency at 85.51 ± 1.69 % but the difference was not significant compared to the other CWs. C. Ávila et al. [33] reported an $NH_4^+$ removal capability of 87.0 % in CWs using gravel material. Another study indicated that $NH_4^+$ removal efficiencies achieved with river rock filters ranged from 58.7 - 68.9 % [34]. $NH_4^+$ removal efficiency can vary with different filter materials. Alternative filter materials may improve $NH_4^+$ removal through physical adsorption and biological nitrification processes [12]. M. E. Khalifa, *et al*. [28] reported better $NH_4^+$ removal with plastic (66 %) compared to gravel (57 %) or rubber (54 %), due to better nitrifying bacteria activity and oxygen supply in the plastic-containing filters. In this study, a significant difference was noted with the addition of rice husk and plastic in CW4, showing the highest removal rate among the four SSF CW models. However, it is important to note that the ultimate goal of wastewater treatment is to meet the allowable standards. The average post-treatment $NH_4^+$ values in CW1, CW2, CW3, and CW4 were 4.7 ± 0.93; 4.87 ± 0.54; 4.17 ± 0.65, and 3.9 ± 0.57 mg/l, respectively, meeting the QCVN 40:2011/BTNMT, column B standards (Figure 6, Table 4).

In this study, the differences in TP (total phosphorus) treatment efficiency of different filters were evaluated. The highest TP removal efficiency was observed in CW4 at 82.22 ± 2.51 %, and the lowest was in CW1 at 68.88 ± 4.29 %. Filters containing plastic showed different TP removal efficiencies compared to similar filters containing limestone. The treatment efficiency ranked as CW4 > CW3 and CW2 > CW1 ($p < 0.05$).

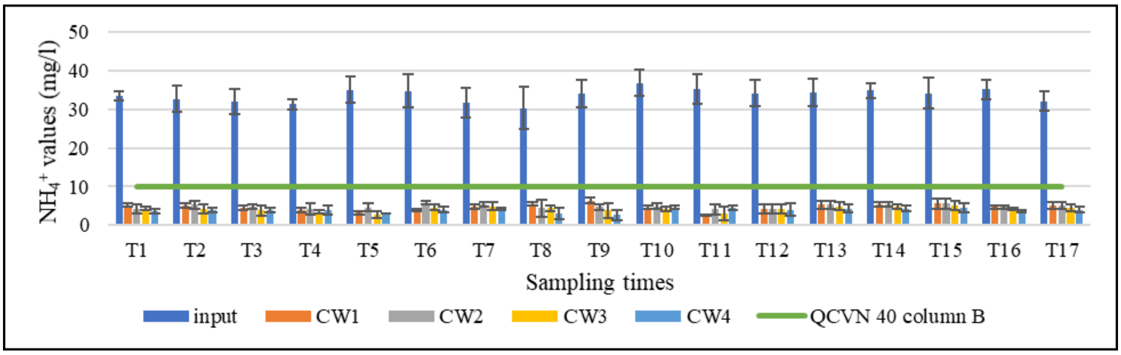

*Figure 6*. NH$_4^+$ values in the inlet and outlet wastewater of the four experimental models.

The main mechanisms of phosphorus removal are based on microbial assimilation, plant uptake, and the physical-chemical reactions of the substrate [35], where the physical-chemical reactions of the substrate are the predominant form of phosphorus removal in CWs [36]. Limestone contains calcium which helps in the adsorption of phosphorus [37], while the phosphorus removal pathway in plastic primarily involves plant uptake, microbial transformations, and the release of anaerobic biological phosphorus [12]. Additionally, experiments with rice husks showed higher efficiencies compared to other CW models. The TP treatment efficiency in the CW systems of this study ranked from highest to lowest as follows: CW4 > CW3, CW2 > CW1 ($p < 0.05$). Similar to nitrogen, phosphorus in wastewater is considered a nutrient source for plants. This might be why CWs containing rice husk – with better plant growth – have higher TP treatment efficiencies. Previous reports indicate CW TP treatment efficiencies ranging from 54 – 64 % [22, 38], with rice husk-containing filters achieving higher efficiencies of 80 - 82 % [25], consistent with CW4. The outlet TP values for CW1, CW2, CW3, and CW4 were respectively 4.56 ± 0.49; 3.6 ± 0.38; 3.17 ± 0.44 and 2.60 ± 0.28 mg/l, consistently meeting the QCVN 40:2011/BTNMT, column B standards throughout the three months of operation (Figure 7).

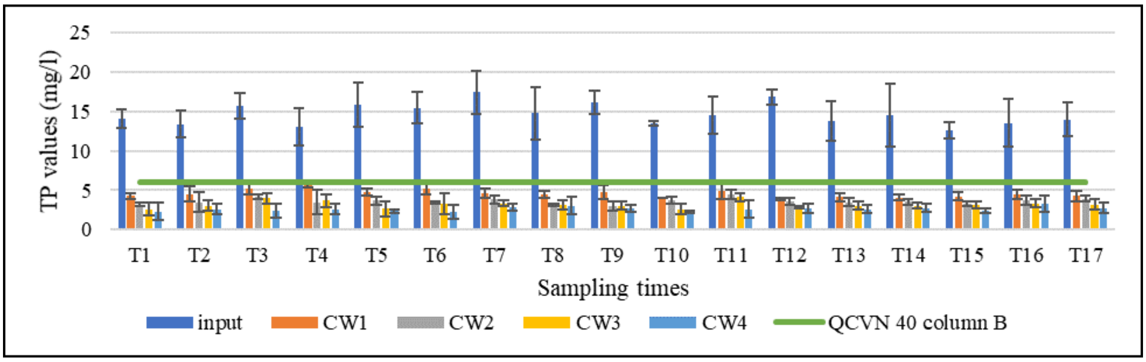

*Figure 7*. TP values in the inlet and outlet wastewater of the four experimental models.

Regarding treatment effectiveness, all four CW models demonstrated unique advantages. The SSF CWs with inorganic filter materials were effective in removing COD and TSS. The highest removal rates of COD and TSS in CW1 were 52.30 ± 1.45 and 17.26 ± 0.33 g.m$^{-2}$.d$^{-1}$, respectively. The COD removal efficiency of CW2 was slightly lower than CW1 ($p < 0.05$), but there was no significant difference in TSS removal efficiency ($p > 0.05$).

This demonstrates that the organic matter treatment capability of plastic waste is comparable to limestone in the same filter. However, in CW3 and CW4, the efficiencies for COD and TSS were consistently significantly lower ($p < 0.05$), highlighting the limitations of rice husk in treating organic matter. This is also a consideration for wastewater with higher COD and TSS values than the studied wastewater if rice husk is used as a filter material. However, nutrient treatment performance in CWs containing rice husk was superior. The highest treatment rates for TN, $NH_4^+$, and TP in CW4 were respectively 5.49 ± 0.4; 2.97 ± 0.16; and 1.2 ± 0.25 g.m$^{-2}$.d$^{-1}$. In CWs containing plastic, TP treatment efficiency was higher than in similar filters containing limestone ($p < 0.05$). The results also indicate a clear difference in nutrient treatment performance between CWs with and without rice husk. Nitrogen was removed at 60 - 96 % through nitrification-denitrification processes [39] and 14.29 - 51.89 % through plant uptake [40]. The absorption by materials, plants, and microorganisms may contribute to phosphorus removal in CWs, where substrate absorption plays a crucial role [37]. Plastic materials facilitate biofilm development, and the addition of rice husk creates an ideal environment for microbial growth [12]. The advantages in plant and microbial growth are the reasons for the higher nutrient treatment performance in the new filters CW3 and CW4.

*Table 4.* Average values of concentrations, treatment efficiencies, and processing rates observed in the CWs

| Parameters | | pH | COD | TSS | TN | $NH_4^+$ | TP |
|---|---|---|---|---|---|---|---|
| Input (mg/l) | | 6.03 ± 0.02 | 623.43 ± 9.72 | 216.89 ± 2.71 | 68.5 ± 3.14 | 33.61 ± 2.5 | 14.64 ± 1.38 |
| CW1 | Output (mg/l) | 7.21 ± 0.12 | 100.42 ± 7.8 | 44.33 ± 3.56 | 23.19 ± 2.82 | 4.7 ± 0.93 | 4.56 ± 0.49 |
| | Removal efficiency (%) | - | 83.89 ± 1.38$^{a}$ | 79.56 ± 1.36$^{a}$ | 66.14 ± 4.82$^{b}$ | 86.02 ± 2.97$^{b}$ | 68.88 ± 4.29$^{c}$ |
| | Removal rate (g.m$^{-2}$.d$^{-1}$) | - | 52.30 ± 1.45 | 17.26 ± 0.33 | 4.53 ± 0.46 | 2.89 ± 0.21 | 1.01 ± 0.14 |
| CW2 | Output (mg/l) | 6.74 ± 0.03 | 109.79 ± 6.09 | 46.41 ± 3.08 | 26.71 ± 2.65 | 4.87 ± 0.54 | 3.6 ± 0.38 |
| | Removal efficiency (%) | - | 82.39 ± 1.04$^{b}$ | 78.6 ± 1.35$^{a}$ | 61 ± 4.44$^{c}$ | 85.51 ± 1.69$^{c}$ | 75.39 ± 3.21$^{b}$ |
| | Removal rate (g.m$^{-2}$.d$^{-1}$) | - | 51.36 ± 1.21 | 17.05 ± 0.33 | 4.18 ± 0.44 | 2.87 ± 0.17 | 1.10 ± 0.14 |
| CW3 | Output (mg/l) | 7.16 ± 0.03 | 131.61 ± 7.80 | 58.43 ± 2.71 | 15.96 ± 1.72 | 4.17 ± 0.65 | 3.17 ± 0.44 |
| | Removal efficiency (%) | - | 78.89 ± 1.42$^{c}$ | 73.06 ± 1.16$^{b}$ | 76.71 ± 2.77$^{a}$ | 87.58 ± 2.08$^{a}$ | 78.32 ± 3.60$^{b}$ |
| | Removal rate (g.m$^{-2}$.d$^{-1}$) | - | 49.18 ± 1.45 | 15.85 ± 0.30 | 5.25 ± 0.36 | 2.94 ± 0.19 | 1.15 ± 0.14 |
| CW4 | Output (mg/l) | 7.16 ± 0.03 | 131.12 ± 5.35 | 58.69 ± 3.26 | 13.61 ± 1.56 | 3.90 ± 0.57 | 2.60 ± 0.28 |
| | Removal efficiency (%) | - | 78.97 ± 0.89$^{c}$ | 72.94 ± 1.44$^{b}$ | 80.14 ± 2.76$^{a}$ | 88.39 ± 1.62$^{a}$ | 82.22 ± 2.51$^{a}$ |
| | Removal rate (g.m$^{-2}$.d$^{-1}$) | - | 49.23 ± 1.06 | 15.82 ± 0.36 | 5.49 ± 0.4 | 2.97 ± 0.16 | 1.2 ± 0.25 |

*Avg ± Stdev*, average ± standard deviation. Within each row, numbers with the same letter are not significantly different ($p > 0.05$) from each other. Data with the letter "a" superscript has higher value than data with "b" or "c".

In the long term, plant growth maintains the stability of the CW. Although there have been many reports on the use of traditional materials like stone, gravel, and sand in nutrient removal, in this study, the SSF CWs were designed with new filters providing more diverse options for enhanced nitrogen and phosphorus removal. The monitored wastewater quality results at the four SSF CWs differed, but all met the QCVN 40:2011/BTNMT, column B standards.

Another aspect evaluated in this report is the cost of materials. Table 5 shows the differences in material costs for each SSF CW.

*Table 5.* Material costs used in the study

| CW Model | Material Cost per Model (USD/m$^3$) |
|---|---|
| CW1 | 13.654 |
| CW2 | 8.275 |
| CW3 | 13.226 |
| CW4 | 7.848 |

*The prices for sand, limestone (10 × 20 mm), gravel (30 × 40 mm), plastic straws, and rice husk are respectively 13.2, 17.21, 11.6, 0, and 1.8 USD/m$^3$. These prices are provided by local dealers in Viet Nam.

Traditional materials such as limestone, gravel, and sand are much more expensive than new materials. CW1 has the highest material cost at $13.654 /m$^3$, while CW4 has the lowest cost at only $7.848 /m$^3$. Rice noodle handicraft villages often operate on a small, decentralized scale, so the budget for environmental treatment is limited. CWs are the most economically viable alternative due to their lower deployment and operational costs. Costs can be further reduced by replacing materials. For instance, in this study, using plastic waste in place of limestone saved up to $17.21/m$^3$ of material; adding rice husk also reduced costs by $0.428 /m$^3$. It should be emphasized that plastic straws and rice husks may otherwise be considered waste and could even incur disposal costs. Therefore, using these materials in the CW filter design is seen as an effective waste reuse solution and reduces environmental treatment costs for plastic waste.

The evaluations have highlighted the importance of choosing the right filter materials. The alternative materials used in the study have demonstrated effective pollution treatment capabilities and also have a cost advantage over traditional materials such as stone, gravel, and sand. Rice husk has limitations in treating COD and TSS but is not a significant concern when applied to wastewater treatment in rice noodle handicraft villages.. The decomposition of plastic also occurs over a long period and may exceed the lifespan of the SSF CW. The release of microplastics from CWs using plastic substrates needs further investigation to ensure the safe use of plastic waste.

## 4. CONCLUSIONS

The findings of this study demonstrate the significant potential of alternative materials such as plastic waste and rice husk in treating wastewater from rice noodle handicraft villages using SSF CWs. Plastic waste can replace limestone without significantly affecting performance and plant growth. Meanwhile, the addition of rice husk significantly enhanced the treatment efficiency of N and P, and promoted the growth of plants (*C. alternifolius*). A deeper examination of cost aspects and environmental benefits shows the advantages of using plastic waste and rice husk materials. This study has provided a specific assessment of partially replacing traditional filter materials (stone, gravel, sand) with alternative materials in the design of SSF CWs. CW4 (including sand, rice husk, plastic waste, gravel) has the treatment efficiency that meets the permitted standards and low cost, suitable for treating wastewater in Vietnamese rice noodle handicraft villages.

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