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Constructed Wetland Enhancement via Chemical Coagulation using variable Hydraulic Retention Times for wastewater Treatment

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Abstract

Treatment of municipal wastewater using constructed wetlands has huge advantages as green, low cost, effective, environmental friendly and aesthetic advantages. Therefore, adequate treated wastewater can be considered as an unconventional water resource according to the quality of final treated effluent. Meanwhile, separation of municipal wastewater into grey, black, and yellow water reduces the pollution parameter in the separated grey water remarkably. In this respect, grey water becomes much simpler to be treated in terms of pollution parameters removal. The treated effluent, therefore, can be reused for agriculture purposes according to the quality of the final treated effluent.

The aim of the present work is to investigate the treatment of grey water via sedimentation in combination with chemical coagulation using lime and ferric chloride followed by a hybrid constructed wetland. The hybrid constructed wetland consisted of horizontal subsurface follow (SSF-CW), followed by vertical flow constructed wetland (VF-CW). The hydraulic loading rate (HLR) of 170, 85, and 56.6 $m^3ha^{-1}.day^{-1}$with corresponding to organic loading rates (OLR) of 717.4, 358.70, and 239.13 kg BOD_5 $ha^{-1}.day^{-1}$ at variable retention times namely (1, 2, and 3 days) were examined. The COD, BOD_5, and TSS were reduced by 90.42, 90.65, and 91.4% respectively at the hydraulic residence time (HRT) of 3 days. At HRT of 2 days, on the other hand, the recorded removal rates were 90.83, 89.82, and 91.1%, respectively. The characteristics of the treated effluent using the two days HRT, and three days HRT were both in accordance with the Egyptian law of discharging the treated wastewater into the sewerage networks, as well as the Egyptian code of reuse in agriculture for restricted purposes.

Keywords: Hybrid constructed wetland, chemical coagulation, Hydraulic loading rate (HLR), Organic loading rates (OLR), water reuse, Egyptian code of water reuse

1. INTRODUCTION

The global wide water scarcity increases due to the increasing population and human activities all over the world[1][2].Human activities include discharge of domestic and industrial wastewater discharge to the environment without adequate treatment. Domestic wastewater that is produced from homes, hotels, and other institutions and can be classified to grey and black water[3][4].Black water includes urine and feces[5]. On the other hand, grey water includes the outlet from the bathroom, laundry, washing machines and kitchen activities[6][7].

General speaking, domestic wastewater treatment processes could be achieved by three stages, namely; primary, secondary, and tertiary stages. In the primary stage, large and medium particles can be removed by gravity and /or settling, where the suspended matters are removed. The secondary treatment can be performed biologically to break down the organic materials or mechanically byfiltration and / or activated sludge (i.e. anaerobic treatment, oxidation ponds, and / or holding ponds)[8][9]. Furthermore, the tertiary treatment is one of the advanced methods used to remove certain pollutants, in which the disinfection process can be carried out by adding chlorine, ozone, or by ultraviolet (UV)[10].

The sedimentation tank (ST) acts as the primary treatment step for the influent wastewater to prevent clogging as well as improving the treatment process. During this treatment, heavy materials can be settled down to the bottom of the tank as sludge. In this respect, the accumulated sludge in the sedimentation tank should be removed regularly[30].

On the other hand, the coagulation/flocculation process is characterized by being practically cost-effective, simple

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to implement, and efficient [12][13][14]. There are many types of chemical coagulants including inorganic, and polymers. The most common inorganic coagulants are aluminum salts, lime and iron salts, are the most widely used. These coagulants are low cost, available and effective in removing different contaminates. The choice of coagulant depends on wastewater characteristics of the given wastewater, type of the particulates to be removed, cost, the quality of the produced sludge, and the quality of the effluent [12][15].

Coagulation/flocculation process can be accomplished by adding the given coagulants into wastewater. Consequently, rapid cleavage or aggregation of particles and / or rearrangement takes place. This process is carried out through four successive stages: 1- electrical double layer condensation, 2-adsorption and charge neutralization, 3- precipitation, and 4- adsorption and antiparticle bridging [15] [16]. Such coagulation and flocculation mechanisms depend on the type of formed charge on formed suspended solids in the given wastewater. In this respect, if the suspended solids have the same charge of the particle surface, then a repulsion force will be established when they come close to each other. Consequently, the treatment process could not be performed [9[]10[]15]. On the contrary, the formation of different charged particles could easily stick together as flocks and the small suspended particles will stick to each other forming larger particles (flocks) that are comparatively heavy enough to settle down as a precipitates [9][15]. Moreover, the particles of small masses will be collided to produce larger masses in size and weight until the macro flocks are formed and ready for precipitation [15].

Iron salts are widely used in wastewater treatment, in which the soluble ferric hydroxide is produced [17][18].

There are several advantages of using ferric chloride as a low cost coagulant in wastewater treatment with respect to removing turbidity, colour, organic and inorganic contaminants [17][19]. The coagulation reaction; in this respect; is most effective at a lower pH values around 5.0 [20][21]. On the other hand, the lime is one of the most commonly used chemicals for pH adjustment and water stabilization. Lime is characterized by its low cost and higher density [11].

On the other hand, constructed wetlands (CWs) systems proves to be effective, low cost in construction, simple, low labor requirement, low-energy requirement or no energy at all, low cost in operation and maintenance [13][14]. The CWs are defined as engineered systems that have been designed and constructed to utilize natural processes involving wetland vegetation [25].The treated effluent will be of better quality, suited for reuse in land irrigation according to the final treated effluent. Besides, they are environmentally friendly systems, has no contact with the wastewater, and no noise as compared with many other wastewater treatment techniques. There is no odor either, the system works effectively to reduce pathogenic bacteria, and thus making it a lot safer to be on-site [26]. CWs possess the microbial assemblages to assist in treating wastewaters, and the biochemical transformation of pollutants. The CWs are biologically productive and self-sustaining [11].

Relatively larger space, and sunlight are required for CWs [27]. CWs are very simple in operation[29]. There are several parameters selected for designing CWs that depend mainly on the type of wastewater, climate, surface area (A), oxygen input, and oxygen consumed, the detention time (t), depth of the CW's bed (d), and the depth of substrate (d) [30], the hydraulic loading rate (HLR), organic loading rate (OLR) and relatively the employed vascular plants [29][30].

The substrates must have high porosity (comparative with the HLR), and chemical stability [36].The substrates must be inert materials such as sand, and gravel [30], the organic material such as mulch, rice husk, and oak leaf [34]. The substrate should not contain loam, silt, and fine material [36]. The efficiency of the substrate depends on the HLR, OLR, type of wastewater, and grain size (porosity) of the substrates[53]. The slope of the substrate is 1 % to facilitate the wastewater flow[7].

Different vascular plants can be employed in the CWs such as *Pragmatis Australia*, and the *Typha*, Papyrus sedges, *Heliconia*, *Canna lily*, Reeds, *Cyperusaltostratus*, etc., [35]. These Vascular plants can be classified into three types, floating, emergent, and, submerged. The emergent plants grow on water-saturated or submerged soil. The floating plants float on the water surface. The submerged plants grow with both steam and leaves [37].Planting density is usually about 4 to 6 rhizome/m^2.

The basic classification of the CWs is the wastewater flow direction. This includes four types flow, namely: sub-surface flow (SSF-CW), horizontal flow (HF-CWs), vertical flow (VF-CWs), and hybrid systems (HF+VF). The hybrid systems are combined from two different classes of CWs such as (FWS-CW), and (VF-CWs)[25][26][31][32].[33][34]. There are certain limitations with the use of CWs; this is the needed to certain land area than other wastewater treatment plants.

It is worth mentioning that the efficiency of CWs treatment systems may vary seasonally in response to changing environmental conditions, including rainfall. The substrates may be clogged if inlet wastewater is not well primary pretreated [42]. The removal of pollutants in CWs is a complicated process mainly, including sedimentation, filtration, volatilization, adsorption, plant uptake, and microbial elimination[40][25]. The advantages of the FWS-CW are the following: high removal efficiency of suspended solids, organic matter, nutrients (N & P), and high efficiency of the plants to transport oxygen from the air to the root zone. Uptake of the nutrients elements by the plants including (N & P) [3]. The FWS-CW maintenance cost is very low.

Nevertheless, the disadvantage of FWS-CWs requires a larger land area [36].

The performance of CWs for pollutants removal depends on the design, and operating factors such as the hydraulic loading rate (HLR), the hydraulic retention time (HRT), sunlight exposure, and organic loading rate (OLR)[27]. The (HRT) for the treatment of CWs is the average time that water remains in the wetland's bed[38][39]. The HRT depends on many factors such as the flow rate, the type of plants, as well as the porosity of the used substrate[25]. In addition, the short circuit occurs due to the clogging of the inlet zone in the CWs, which leads to lower treatment efficiency because of the decreased ability of the pollutants by the biofilm [36].The HLR refers to the loading on a water volume per unit area basis [4][11].

The aim of this work is the enhancement of the hybrid constructed wetlands for treatment of grey water using successive treatment techniques namely sedimentation process enhanced by chemical coagulants (using $FeCl_3$ in combination with lime), followed by a hybrid constructed wetland. Meanwhile, the effect of variable hydraulic loading rate (HLR) of the constructed wetland was examined in terms of the efficiency on the treatment process. The hydraulic loading rate (HLR) at (1, 2, and 3 days) was applied. The implemented hybrid wetland consisted of horizontal subsurface flow (SSF-CW) followed by vertical flow (VF-CW).

2. Materials and Methods

2.1. Site description

The source of the separated domestic wastewater was connected from a house across the street from the National Research Centre, the experimental pilot plant sites. This domestic wastewater was separated by piping systems into black water, and grey water. The black water is the source of the toilet including the fasces, urine, and toilet flushing. The grey water consists of the water from the shower, wash basins, laundry, and the kitchen. The grey water source was connected by piping system beneath the street to a manhole located in the pilot plant site. Grey water is the subject of the present work.

2.2. Sedimentation System

For the purpose, two sedimentation successive tanks of the volume of 1x1x1 m each were placed at high level. Both tanks were connected to each other. The first one was placed at 4.4 m height and second at 4.0 m. Each tank was designed to be baffled into 3 small rooms. The grey water was raised from the Manhole to the first tank by piping system using electric pump. The grey water was left in the 1st tank for few minutes to be flowing by gravity to the second sedimentation,

2.3. Coagulation/flocculation and Sedimentation

Jar tests were performed using grey water samples. Different doses of ferric chloride ($FeCl_3$, 98 %, Merck), (1, 5, 10, 20, 30, 50, and 70 mg/L) and constant dose of lime (10 mg/L) were tested. Flash mixing at 200 rpm for 30 sec., followed by flocculation for 20 min, was carried out. The physical and chemical characteristics namely: chemical oxygen demand (COD), Biological oxygen demand (BOD_5), Phosphate (PO_4) and total suspended solid (TSS) of the raw grey water, and the successive coagulated samples were determined. These processes were repeated three times. The optimum doses of $FeCl_3$ were determined. These procedures repeated with the optimum dose of $FeCl_3$ and different doses of lime (10, 20, and 30 mg/L), the optimum doses of lime and $FeCl_3$were determined by chemical analyses of samples before and after coagulants addition in order to determine the optimum dose of the $FeCl_3$ and the lime. The optimum doses were added to the sedimentation tank. The chemically coagulated effluent was directed to the horizontal constructed wetland (H-FWS).

2.3. The Horizontal Flow Constructed Wetlands (H-FWS)

The H-FWS was employed as a secondary treatment. The effluent of (H-FWS) was fed to the vertical flow wetland (V-FWS). The V-FWS was the final step in wetland system. The dimensions and operating conditions of H-FWS are 2.0min length, 0.60 m width, 0.50 m depth (substrate). Both H-FWS and V-FWS are planted with *REEDS* [46] [58]. The No. of rhizomes per m^{-2} is 3.0. The porosity of gravel is 0.34.

The effect of the different Hydraulic Residence Time (HRT) was examined, namely: 1, 2, and 3 HRT. The corresponding Hydraulic loading rate (HLR) was 170, 85, and 56.6 $m^3ha^{-1}.day^{-11}$ which are corresponding to (1, 2, and 3) days respectively. The organic load (OLR Avg.) was 717.40, 358.70 and 239.13 g BOD_5 $ha^{-1}.day^{-1}$ at (1, 2, and 3) days respectively.

2.4. Calculations of design H-FWS

The studied HRT's were determine for each wastewater sample per day according to equations (1, 2, 3) [10]:

$$Q = \frac{A\,.\,d.\,\eta}{t} \quad (1)$$

$$OLR = \frac{C.\,d.\,F1.\,\eta}{t.\,F2} \quad (2)$$

$$HLR = \frac{Q}{A} \quad (3)$$

Where Q is the flow rate m^3/day, A is surface area m^2, d is the depth of substrate (m), h is the substrate porosity (unit less), and t is detention time per day. The C is a concentration of BOD_5 of the influent, as (mg/L), F_1 is the constant = 0.001 $kg.g^{-1}$, and F_2 = 0.0001 $ha.m^{-2}$is constant.

2.5. Determination of the physical and chemical Characteristic of grey wastewater

The samples were collected in glass bottles from the raw grey water, the effluents of coagulation process, H-FWS, and V-FWS. The analysis was repeated three times. The physicochemical analysis was performed according to standard methods for the examination of water and wastewater, American Public Health Association (APHA)[47]. The studied parameters of the grey water characteristics included the ammonia, COD, BOD_5, TN, TKN, turbidity, organic nitrogen, nitrate, oils & greases, phosphate, TSS, pH, and dissolved oxygen (DO).

3. Results and discussion

3.1. Characteristics of the raw grey water

The COD and BOD_5 ranged from 670 to 770 mg/L and 385 to 460 mg/L, respectively. The TSS and oil & grease varied from 401 to 475 mg/L and from 95 to 133 mg/L, respectively. Turbidity ranged from 111.2 to 128 NTU. The ammonia, nitrate, nitrite, and Kjeldahl nitrogen in this raw greywatervaried from 4.8 to 5.3 mg/L, 0.8 to 1.05 mg/L, zero mg/L, and 19 to 35 mg/L, respectively. Total phosphate in the greywater varied from 7.1 to 10.5 mg/L[46].

3.2 Coagulation/Flocculation and sedimentation process of grey water

3.2.1 Effect of $FeCl_3$

By adding the $FeCl_3$, the pH of studied samples decreased by increasing the $FeCl_3$doses[48].

3.2.1.1 Elimination of the COD, TSS, turbidity, and BOD_5

Figure (1) presents the performance of different $FeCl_3$ doses on the removal of COD, BOD_5, and TSS. By adding 30 mg/L of $FeCl_3$, the results of COD, BOD_5, and TSS became 713, 425, and 518 mg/L respectively. The mechanism of this process can be attributed to the formation of the colloidal particles at a negative charge. The colloidal particles are often stable and resistant to aggregates due to the electrical repulsion of the surface charge. The addition of coagulant interacts with the negatively charged colloid in the grey water. The coagulant forms of hydrolyzed species. Fe^{3+} of $FeCl_3$ according to equation (4)[50]. At the removal of turbidity (measured by HANNA instrument), the ferric chloride can be used to generate inorganic cations and anionsions, these ionsin combination with CaOenhanced the formation of the flocscoagulants particles which in turns increases the removal of turbidity [50].

$$Fe + 3OH^- \longrightarrow Fe(OH)_3 \quad (4)$$

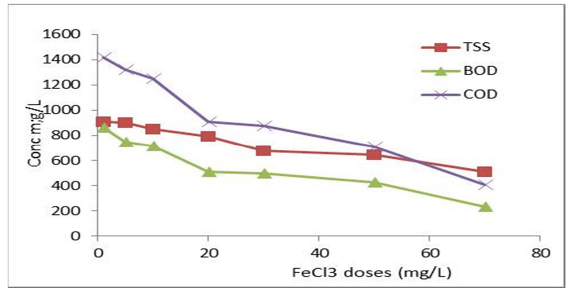

Figure (1): The level of COD, BOD_5, and TSS after adding $FeCl_3$ as coagulant doses (1, 5, 10, 20, 30, 50, and 70) mg

3.2.1.2 Removal of nitrogen and phosphate

The effect of $FeCl_3$ at variable doses on the removal of NH_4^+, $\mathbf{PO_4^{3-}}$, NO_3^-, and TKN is shown in Figure (2). In this respect, the sedimentation processes plays a vital role in the removal of the nitrogenous species. The NH_4^+, $\mathbf{PO_4^{3-}}$, NO_3^-, and TKN can be removed from grey water by volatilization of ammonia gas (NH_3),

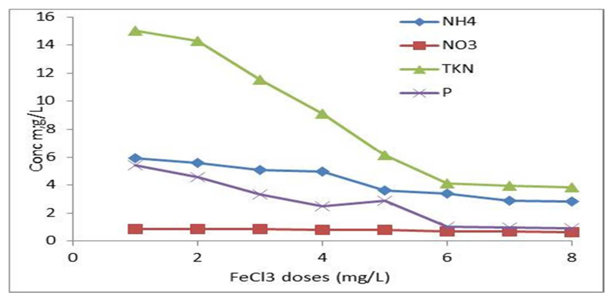

Figure (2): The variations values of NH_4^+, PO_4^{3-}, NO_3^-, NO_2^- and TKN after adding variable does of $FeCl_3$ doses, namely (1, 5, 10, 20, 30, 50, and 70) mg/l

3.2.2. Effect of Lime (CaO)

The different doses of CaO were added, namely 10, 20, and 30 mg/L.These doses were prepared by dissolving 5.0 g CaO in a liter of distilled water as stock solution. The studynwas carried out using Jar test. The best performance of CaO aided with $FeCl_3$ was observed at 30mg/L as shown in Figures (3, 4). The removal mechanisms may be attributed to the charge and stabilization of colloidal particles. CaO and $FeCl_3$ are rapidly hydrolyzed in water to give a range of products including cationic species[51], which can adsorbed by negatively charged particles and neutralize their charge so that flocculation can occur [64][65].

3.2.2.1 Removal of COD, TSS and BOD_5

The variation of COD, BOD_5, TSS and turbidity after the addition of $FeCl_3$ aided with CaO are shown in Figure (3). The removal efficiency (R) of COD, BOD_5, TSS, and turbidity was 60.0%, 60.8 %, 62.1 %, and 61.6 %, respectively. The decrease of COD, BOD_5, TSS, and turbidity by lime can be attributed to the precipitation of soluble organics with the coagulants. The removal of COD and BOD_5 due to biodegradability of organic pollutants [53][54]. The removal of total suspended solids **(TSS)** in these systems by the flocculation and settling of colloidal particulates [55]. The CaO is characterized by a high positive charge and high effective interactions with colloidal particulates that form a positive charge. The latter is able to enhance, increase flocculation, and settling processes, thus and decreases the turbidity[20][32].

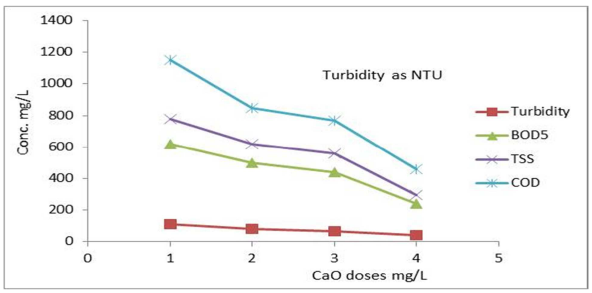

Figure (3): Variations values of COD, BOD_5, turbidity, and after CaO doses (10, 20, and 30) mg

3.2.2.2 Removal of nitrogen and phosphate

By adding a variable doses of $FeCl_3$ aided with CaO, the level of NH_4^+, PO_4^{3-}, NO_3^-, NO_2^-, and TKN were decrease as shown in Figure (4). The total nitrogen, Org. N, NH_4^+, NO_3^-, TKN, and PO_4^{3-} after adding 30 mg of CaO decreased from 14.94 to 3.26, 7.60 to 2.16, 6.40 to 0.98, 0.94 to 0.12, 14.0 to 3.14, and 6.17 to 1.49 mg/L, respectively. The corresponding removal rate of TN, Org. N, NH_4^+, NO_3^-, TKN, and PO_4^{3-} was 78.17 %, 71.50 %, 84.68 %, 81.23 %, 77.57 %, and 75.85 %, respectively. The removal of the nitrogen compounds namely: TN, NH_4^+, NO_3^-, TKN, and Org. N is recorded with respect to the variable pH values and the added CaO[54].Particularly, the TKN and NH_4^+ were removed from grey water by the addition of CaOaccording to the equation (5).The optimum dose showed a slight decrease in the NH_3-N removal due to stabilization of colloids and re-dispersion of the colloidal particles [27].

Another study by (Mena et al, 2008) found that the percentage of NH_3-N removal was relatively the same for both Ca $(OH)_2$ and NaOH which was up to 45% and 48%, with optimum dosage of 6 g/L and 8 g/L, respectively. The recorded pH for $Ca(OH)_2$ and NaOH was pH=12.40±0.02 and pH=12.83±0.02, respectively[8].

$$2NH_4^+ + Ca(OH)_2 \longrightarrow 2NH_3\,(g) + 2H_2O + Ca^{2+} \quad (5)$$

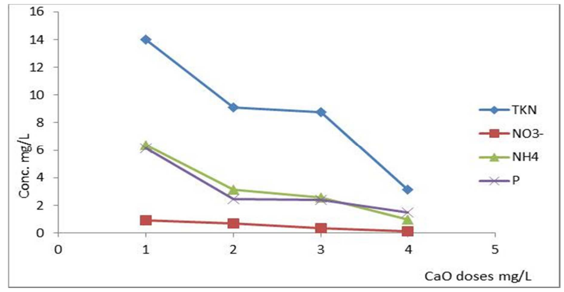

Figure (4): Variations values of NH4+, NO3-, TKN, andPO43-after CaO doses (10, 20, and 30) mg

3.3 The Subsurface Flow Constructed Wetland System (SSF-CWs)

3.3.1 The First Experimental work (HRT) at 24 hrs).

3.3.1.1 Removal of COD, TSS and BOD_5

The effluent values of COD, BOD_5, TSS, and turbidity were measured at hydraulic retention time (HRT) at 24 hrswere 82, 47, 44, mg/L, and 40 NTU (Nephelometric turbidity) respectively. The obtained characteristics of the treated wastewater were not complying with the Egyptian Environmental Association Affair (EEAA) limits for COD, BOD_5, and TSS. These parameters were 80, 40, and 40 mg/L, respectively. The removal of COD, BOD_5, TSS, and turbidity were 8.61%, 88.88%, 89.95%, and 66.56%, respectively, as presented in Figures (5-8). The **TSS** was decreased by gravity sedimentation, and adsorption on biomass film attached to gravel and roots and this can reduce the level of **COD and BOD_5.** Organic matter is decomposed in constructed wetlands by both aerobic and anaerobic microbial processes and by sedimentation and filtration [37]. The removal efficiency in this experiment is low which is attributed to the low detention times (24hrs), and the aerobic and anaerobic microbial processes, sedimentation, and filtration process in SSF-CWs were relatively insufficient[37].

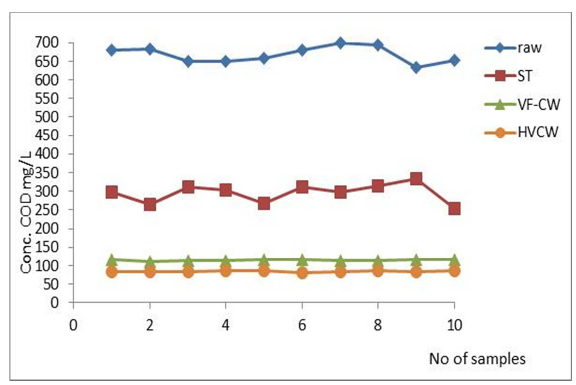

Figure (5): Variation values of COD in wetlands system for COD of raw grey water, COD of sedimentation tank, COD of HF-CWs, and COD of VF-CWs

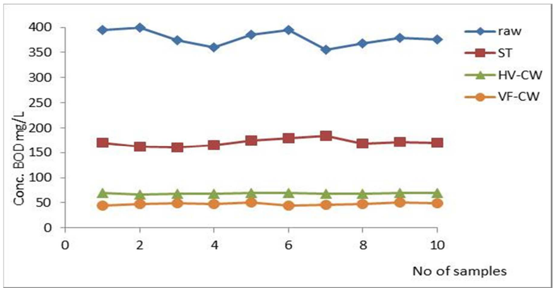

Figure (6): Variation values of BOD5 in wetlands system for BOD5 of raw grey water, BOD5 of sedimentation tank, BOD5 of HF-CWs, and BOD5 of VF-CWs

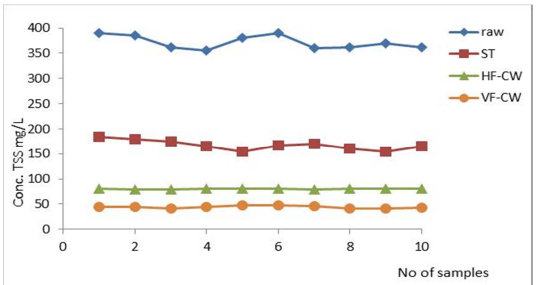

Figure (7): Variation values of TSS in wetlands system for TSS of raw grey water, TSS of sedimentation tank, TSS of HF-CWs, and TSS of VFCWs

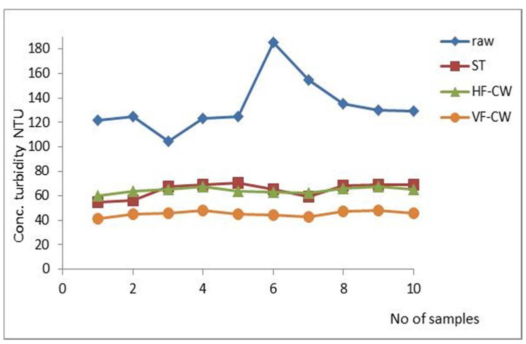

Figure (8): Variation values of turbidity in wetlands system for turbidity of raw grey water, turbidity of sedimentation tank, turbidity of HF-CWs, and turbidity of VFCWs

3.3.1.2 Removal of nitrogen and phosphate

The values of NH_4^+, PO_4^{3-}, NO_3^-, and TKN values in SSF-CWs effluent are presented in Figures (9-12). The removal of TN, Org. N, NH_4^+, PO_4^{3-}, NO_3^-, and TKN removal were63.81%, 64.37%, 66.40%, 79.47%, 50.76%, and 65.18%, respectively. **Phosphate** (PO_4^{3-}) was removed in the SSF-CWs due to plant uptake and the utilization by microorganisms and precipitation in the gravel substrate. The short circuit of HRT 24 hrs, reduces the performance of constructed treatment wetlands [56]. The aammonium compound (NH_4^+) was efficiently removed in constructed wetlands due to the ammonification process followed by nitrification and de-nitrification[27].

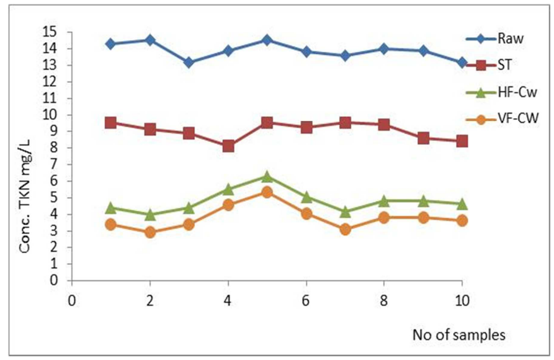

Figure (9): Variation values of TKN in wetlands system for TKN of raw grey water, TKN of sedimentation tank, TKN of HF-CWs, and TKN of VFCWs

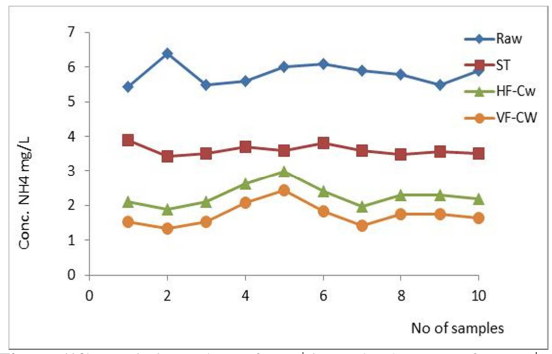

Figure (10): Variation values of NH_4^+ in wetlands system for $NH_4^+$of raw grey water, $NH_4^+$of sedimentation tank, $NH_4^+$of HF-CWs, and $NH_4^+$of VFCWs

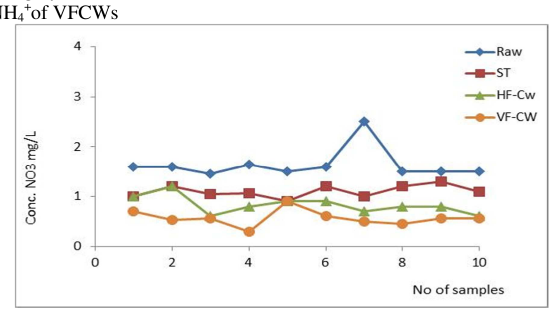

Figure (11): Variation values of NO_3^- in wetlands system for $NO_3^-$of raw grey water, $NO_3^-$of sedimentation tank, $NO_3^-$of HF-CWs, and NO_3^- of VFCWs

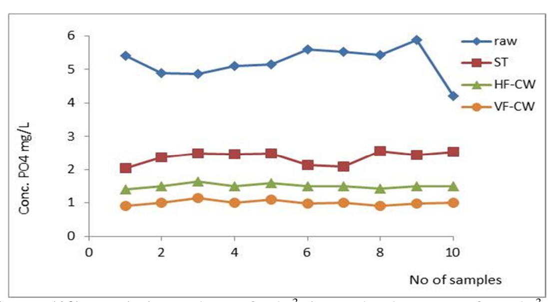

Figure (12): Variation values of PO_4^{3-} in wetlands system for PO_4^{3-} of raw grey water, PO_4^{3-} of sedimentation tankPO_4^{3-} of HF-CWs, and PO_4^{3-} of VFCWs

3.3.2. The Second Experimental (HRT = 48 hrs.)

3.3.2.1. Removal of COD, TSS and BOD_5

The objective of this experiment was to evaluatethe performance of the SSF-CWs at HRT = 48 hrs. The removal efficiency of CWs at (HRT = 48 hrs) for removal of COD, BOD_5, turbidity, and TSS were 90.83 %. 89.82 %, 83.22 %, and 91.10 %, respectively. The values of COD, BOD_5, turbidity, and TSS values in SSF-CWs effluent are presented in Figures (13-16). The **COD, and BOD_5** were degraded aerobically and an aerobically by the bacteria attached to rhizomes Reeds, and substrate [37]. The COD and BOD_5 associated with settable solids in grey water were also removed by sedimentation while microorganisms and interactions with the plant roots remove the colloidal and soluble form COD and BOD_5The aerobic conditions in roots zone facilitated and increase the degradation of organic matters. The total suspended solid (TSS) was not mainly removed in the sedimentation tank. Most of the TSS concentration was removed by filtration and settlement[37]. The removal of **turbidity** is low due to the high degradation of compounds by microorganisms and filtration by gravel substrate[45]. The results indicates the low efficiency of HRT = 48hrs, as a low detention time.

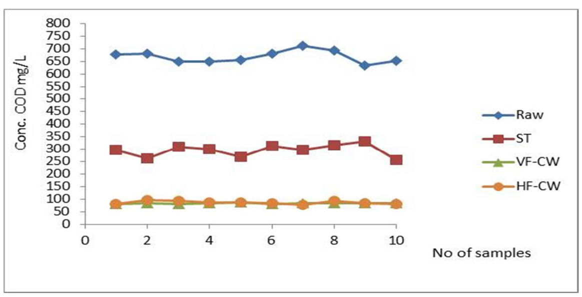

Figure (13): Variation values of COD in wetlands system for COD of raw grey water, COD of sedimentation tank, COD of HF-CWs, and COD of VF-CWs

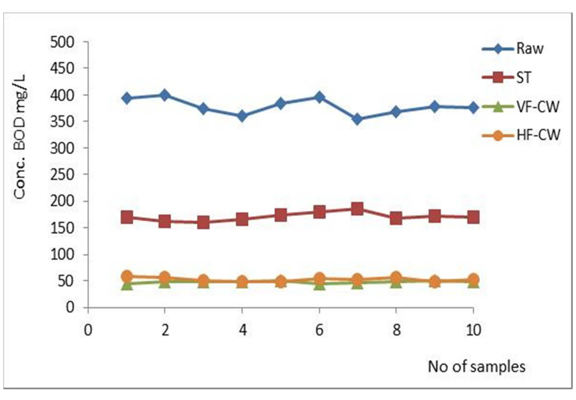

Figure (14): Variation values of BOD_5 in wetlands system for BOD_5 of raw grey water, BOD_5 of sedimentation tank, BOD_5 of HF-CWs, and BOD_5 of VF-CWs

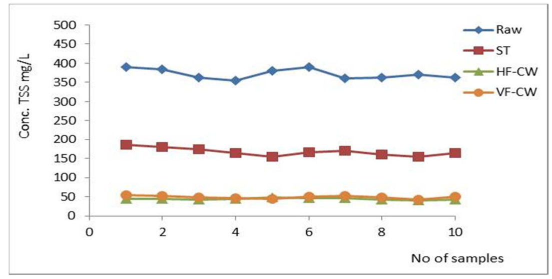

Figure (15): Variation values of TSS in wetlands system for TSS of raw grey water, TSS of sedimentation tank, TSS of HF-CWs, and TSS of VF-CWs

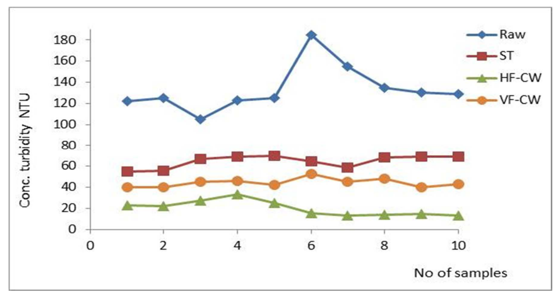

Figure (16): Variation values of turbidity in wetlands system for turbidity of raw grey water, turbidity of sedimentation tank, turbidity of HF-CWs, and turbidity of VF-CWs

3.3.2.2. Removal of nitrogen and phosphate

The values of NH_4^+, PO_4^{3-}, NO_3^-, and TKN values in SSF-CWs wetland effluent are presented in Figures (17-20). The NH_4^+, NO_3^-, TKN, and Org. N were reduced in corresponding to nitrification/de-nitrification in the SSF-CWs. The oxygenation process in SSF-CWs by plants was insufficient at low detention times (48 hrs), and incomplete nitrification (oxidation of ammonia to nitrate). This is the major reason for limited nitrogen removal[37]. Phosphate (PO_4^{3-}) removal, on the other hand, could be mainly attributed to plant uptake utilization by microorganisms and precipitation in the gravel substrate. However, the low detention times was insufficient, and incomplete for precipitation, plant uptake utilization, and microorganisms[14].

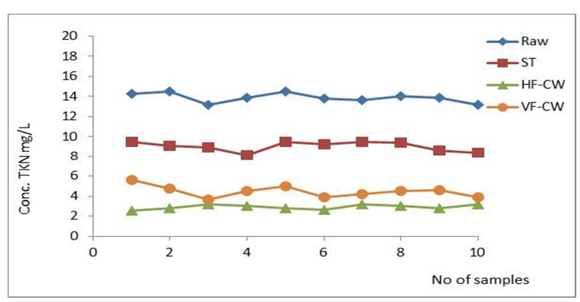

Figure (17): Variation values of TKN in wetlands system for TKN of raw grey water, TKN of sedimentation tank, TKN of HF-CWs, and TKN of VF-CWs

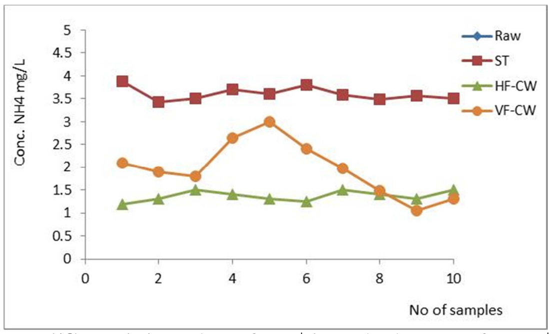

Figure (18): Variation values of NH_4^+ in wetlands system for $NH_4^+$of raw grey water, NH_4^+ of sedimentation tank, NH_4^+ of HF-CWs, and NH_4^+ of VF-CWs

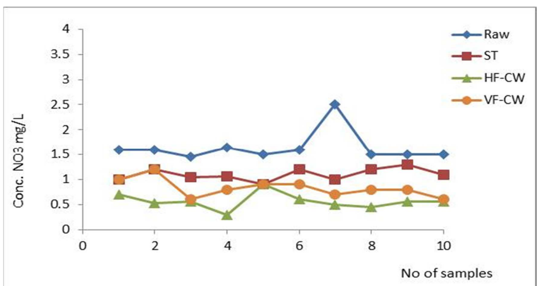

Figure (19): Variation values of NO_3^- in wetlands system for NO_3^- of raw grey water, NO_3^- of sedimentation tank, NO_3^- of HF-CWs, and NO_3^- of VF-CWs

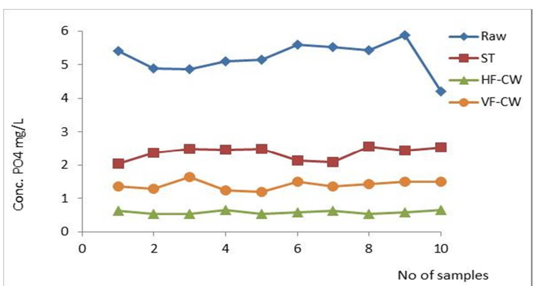

Figure (20): Variation values of PO_4^{3-} in wetlands system for PO_4^{3-} of raw grey water, PO_4^{3-} of sedimentation tank, PO_4^{3-} of HF-CWs, and PO_4^{3-} of VF-CWs

3.3.3. The Third Experimental (HRT = 72 hrs.)

3.3.3.1. Removal of COD, TSS and BOD_5

The objective of this experiment was to the determine performance of the SSF-CWs at HRT = 72 hrs. This study repeated three times. The removal efficiency of this CWs for removal of COD, BOD_5, TSS, and turbidity were 90.42%, 90.65%, 91.41%, and 92.53%, respectively [46]. The data exhibited better treatment efficiency in terms of organic compounds, turbidity, and suspended solids removal. Such removal efficiency of COD and BOD_5 can be attributed to the high detention times namely: HRT = 72 hrs; which supported enough time to improve the hydrolysis and biodegradation of organic matter contents of the studied grey water[46][60]. The removal of COD and BOD_5 is a biological, chemical, and physical treatment process. An important factor in the operation of any biological system is the oxygen supply. The roots would provide an additional surface for biofilm and increases the oxygen supply in the system [46][71]. The simple bacteria decompose the organic pollutants that present in the grey water. Through their degradation, the organic pollutants are transformed into cellular mass [29]. The TSS was removed by the physical processes such as sedimentation and filtration followed by aerobic microbial degradation in the substrate[20]. The TSS was removed throughout the wetlands system due to the filtrations process in the substrate gravel. The filtration process occurs by the effect of particles onto the roots or the gravel in the SSF-CWs [24]. The turbidity may be attributed to the presence of particulate and organic matters in wastewater. The removal of turbidity may be achieved by the degradation of compounds that were carried out by the effect of microorganisms as well as the effect of gravel substrate filtration[46][72].

3.3.3.2 Removal of nitrogen and phosphate

Level of the total nitrogen (TN), organic nitrogen (Org. N), ammonia (NH_4^+), phosphate (PO_4^{3-}), nitrate (NO_3^-), and total Kjeldahl nitrogen (TKN) were 98.11%, 99.38%, 96.30%, 98.80%, 97.65%, and 98.16%, respectively. The removal of TN, Org. N, NH_4^+, PO_4^{3-}, NO_3^-, and TKN through the wetland system involves a series of complex transformations including nitrification, and de-nitrification [46][59]. The major part of nitrogenous compounds removed is attributed to the process of nitrification/de-nitrification [26]. Also, the level of PO_4^{3-} was reduced in the wetland system by sedimentation and filtration by gravel, and uptake by plants [60]. The nitrogen and phosphorus uptake by plants is not a significant process for are taken and released in the cycle of plant's growth and death[60].

3.4. Comparison between three cases (SSF-CWs)

The obtained results indicated that the SSF-CWs at HRT of 72 hrs are more effective in NH_4^+, PO_4^{3-}, NO_3^-, Org. N, TKN, TN, turbidity, COD, BOD_5, and TSS removal than at the HRT 48 hrs, and 24 hrs, due to the relatively low velocity and better distribution of the influent water. The mean residual concentrations of NH_4^+, PO_4^{3-}, NO_3^-, Org. N, TKN, T.N, COD, BOD_5, TSS, and turbidity at HRT of 72hrs were 0.19, 0.06, 0.03, 0.05, 0.23, 0.26, 69, 39, 37.63 mg/L, and 8.94 NTU, respectively. While at HRT of 48 hrs, the residual concentrations were 1.06, 0.55, 0.40, 3.4, 4.46, 4.86, 78, 43, 39 mg/L, and 20.07 NTU, respectively. Finally, at the lowest HRT (24hrs) the residual concentrations were 1.68, 1.08, 0.65, 2.7, 4.38, 5.03, 82, 47, 44 mg/L, and 40 NTU, respectively. Table (1) shows the removal efficiency of treated samples from treatment system. The results that indicate, the reduction of NH_4^+, PO_4^{3-}, NO3-, Org. N, TKN, T.N, COD, BOD_5, TSS and turbidity at HRT of 72 hrs were 96.30%, 98.80%, 97.65%, 99.38%, 98.16%, 98.11%, 90.42%, 90.65%, 91.41%, and 92.53% respectively. At HRT of 48 hrs were 78.80%, 89.54%, 69.70%, 69.80%, 74.80%, 74.06%, 90.83%, 89.82%, 91.10%, and 83.22% respectively. While, at HRT of 24 hrs were 66.40%, 79.47%, 50.76%, 64.37%, 65.18%, 63.18%, 88.61%, 88.88%, 89.95%, and 66.56% respectively. It was clear that the removal efficiency increased with increasing the HRT of SSF-CWs.

Table (1)
Comparison between removal percentages of three cases of the combined coagulation/CWs system

Pollutant	(72h) pollutant removal (R %)				(48h) pollutant removal (R %)				(24h) pollutant removal (R %)			
	ST	HFCWs	VFCWs	Total removed	ST	HFCWs	VFCWs	Total removed	ST	HFCWs	VFCWs	Total removed
PO_4^{3-} (mg/L)	59.8	79.15	85.68	98.80	49.4	47.74	60.43	89.54	53.4	38.37	28.48	79.47
NH_4^+ (mg/L)	18.6	81.08	75.97	96.30	28.0	45.56	45.92	78.80	35.0	38.15	16.42	66.40
NO_3^- (mg/L)	-2.27	67.41	92.95	97.65	37.1	19.28	40.30	69.70	29.5	15.05	17.72	50.76
Org. N (mg/L)	79.2	47.13	94.34	99.38	28.6	28.28	12.37	69.80	12.4	38.86	55.91	64.37
TKN (mg/L)	55.1	71.63	85.50	98.16	28.3	35.18	23.63	74.80	23.7	36.70	42.83	65.18
Total N (mg/L)	49.7	70.82	87.11	98.11	29.2	33.84	25.35	74.06	22.1	36.60	39.94	63.81
BOD_5 (mg/L)	42.9	80.08	17.71	90.65	59.5	69.01	18.87	89.82	45.0	72.41	26.56	88.88
COD (mg/L)	44.1	78.93	18.54	90.42	58.8	70.61	24.14	90.83	94.5	-200.00	29.91	88.61
TSS (mg/L)	50.4	79.72	14.48	91.41	61.6	70.83	20.41	91.10	51.3	71.83	26.67	89.95
Turbidity (NTU)	58.9	36.86	71.16	92.53	46.4	29.69	55.40	83.22	43.9	10.45	33.33	66.56

Note: - No. of samples are 10 samples, R % is removal efficiency :NTU is Nephelometric Turbidity

4. Conclusions

- Greywater becomes simpler to treat and the treated effluent can be re-used for irrigation of many crops. This reduces the loss of a large part of the wastewater.
- The final treated effluent was in compliance with the law of 84 for the year 1982 (concerning the protection of the Nile River) from pollution.
- Treated effluent can be re-used to irrigate many crops according to the Egyptian code for reuse [62].
- The obtained results indicated that the SSF-CWs at HRT of 72 hrs are more effective in NH_4^+, PO_4^{3-}, NO_3^-, Org. N, TKN, TN, turbidity, COD, BOD_5, and TSS removal than at the HRT 48 hrs, and 24 hrs,
- The removal efficiency of NH_4^+, PO_4^{3-}, NO_3-, Org. N, TKN, T.N, COD, BOD_5, TSS and turbidity at HRT of 72 hrs were 96.30%, 98.80%, 97.65%, 99.38%, 98.16%, 98.11%, 90.42%, 90.65%, 91.41%, and 92.53% respectively. At HRT of 48 hrs were 78.80%, 89.54%, 69.70%, 69.80%, 74.80%, 74.06%, 90.83%, 89.82%, 91.10%, and 83.22% respectively. While, at HRT of 24 hrs were 66.40%, 79.47%, 50.76%, 64.37%, 65.18%, 63.18%, 88.61%, 88.88%, 89.95%, and 66.56% respectively.
- It is recommended to use the HF-CW treatment system for the treatment of grey water not less than 48 hrs HRT.

5. Conflicts of interest

There are no conflicts to declare

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2. "*Development of the frame conditions for the establishment of an innovative water technology which couples anaerobic waste water treatment and biomass production in a bioreactor in the Mediterranean region*"- number (31319)- FRAME, ERANETMED3-75, Fund (STDF-Egypt).

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6. 2. Titled "*Development of the frame conditions for the establishment of an innovative water technology which couples anaerobic waste water treatment and biomass production in a bioreactor in the Mediterranean region*"-number (31319)-FRAME, ERANETMED3-75, Fund (STDF-Egypt).

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