

Research Article

Pilot-scale study based on integrated fixed-film activated sludge process for cement industrial wastewater treatment

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Abstract

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Due to the lack of freshwater resources in Egypt, cement wastewater treatment was performed to widen the range of the water used in irrigation to face the massive future water scarcity. In this study, integrated fixed-film activated sludge (IFAS) was used as a biological treatment method. A laboratory pilot was established as a simulation of the IFAS process. The scale-pilot consists of a primary sedimentation tank, an IFAS tank equipped with an air blower, and a final settling tank. Three experimental attempts were performed using 3 different bio-carriers. In the first trial, Luffa sponges were used as natural bio-carriers and polyurethane sponges (PU) as artificial bio-carriers in the second trial, in addition to a combination between Luffa and PU sponges as a hybrid bio-carrier in the third trial. After analyzing the physicochemical properties of wastewater at the national research center in Cairo, the removal efficiency of TSS (total suspended solids), COD (chemical oxygen demand), BOD (biological oxygen demand), TN (total nitrogen), and TP (total phosphorous) was 94.5%, 87.8%, 90.8%, 75.9%, and 69.4%, respectively in case of using the combination between Luffa and PU sponges. It can be concluded that using IFAS process was effective for cement wastewater treatment and the effluent wastewater met the Egyptian code limitations for reuse in agriculture purposes.

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Introduction

Nowadays, water pollution due to wastewater produced from cement industries has been classified as a critical environmental concern. Cement industries consume large quantities of fresh water in different stages of cement manufacturing, which represent 2% of the total Egypt share of freshwater (Abukila, 2015). Despite the lack of freshwater resources in Egypt, massive water consumption can be observed without any considerations of the future water scarcity. So looking for alternatives sources of water became an essential issue. Water plays a key role in cement industries as it is used in several stages, such as cooling

process of cement plant units, washing kilns, and mixing raw materials to form the slurry.

As a result, effluent wastewater was high-strength polluted with organic compounds, nutrients, heavy metals and chemicals such as hydroxides and chlorides, which caused high alkalinity and change in color and temperature, in addition to large numbers of suspended solids, which represent 10% to 20% of the kiln feed captured in the rotary kiln (Kumar and Thakur, 2017). To meet the limitations of the effluent wastewater for reuse in agriculture fields, the application of physical, chemical, and biological treatment is necessary to conserve freshwater in other sectors such as agriculture and drinking water.

Biological treatment is used to remove the organic carbon and nutrients, such as nitrogen and phosphate. Several technologies are used for biological treatment, such as the activated sludge process (ASP), membrane biofilm reactor (MBR), moving bed biofilm reactor (MBBR), and integrated fixed-film activated sludge (IFAS). Each one of the previous technologies has advantages and disadvantages. The activated sludge process (ASP) is the most widely used biological treatment process. ASP is an effective method of biological treatment, but it is not without disadvantages. One of these disadvantages was the low sludge retention time (SRT) that is necessary for biomass to remove the organic matter and nutrients in the basin. ASP needs a large area for its aeration tanks to treat large quantities of wastewater. ASP cannot deal with any fluctuation of sewage loads (Metcalf et al., 1991).

Using a biofilm reactor such as IFAS method is the key to overcome the disadvantages of ASP. In biofilm reactors, biomass attached to the surface of the IFAS media increases the capacity of treatment plants and ensures operational stability (Chen et al., 2008). In IFAS, free-floating carriers are added to the aeration tank to increase the biomass concentration (McQuarrie and Boltz, 2011). IFAS improves the nitrification process by increasing the SRT. Several factors affect the performance of IFAS, such as the biofilm carriers which control the performance and efficiency of IFAS (Chae et al., 2008; Nguyen et al., 2010). So usage of suitable media is very important to achieve better treatment. Factors are affecting the performance of bio-carriers, such as size, shape, surface area, and material (Nguyen et al., 2010). The most popular IFAS media is polyethylene bio-carriers. During using plastic media, some problems have appeared, such as its expensive cost and the harmful effects to the environment because of its wastes. So searching for alternative IFAS media was necessary to overcome plastic media disadvantages. Several natural materials were used as IFAS media, such as zeolite, volcanic ashes, giant reed, gravel, cotton, and Luffa (Dang et al., 2020). In this paper, we will compare the performance of the IFAS process using Polyurethane sponges (PU) as an artificial media and Luffa sponges as a natural bio-carrier.

Luffa is a plant that belongs to the Cucurbitaceae family; it has been used to remove various pollutants from water such as oil, heavy metals due to its high adsorption capacity (Saeed and Iqbal, 2013; Anastopoulos and Pashalidis, 2020), also it has stable chemical and physical properties so that it will not affect water properties, Luffa is renewable and low-cost material. Besides all previous characteristics, Luffa is non-toxic and friendly to the environment (Chen et al., 2018). Luffa sponge is biodegradable, so increasing fiber's durability and service age was improved by immersing it in a lime solution to make it much harder. To increase the adhesion between Luffa fibers and microorganisms, Luffa must be coated with an acrylic-styrene polymer (Dang et al., 2020). PU

sponge is a high-performance adhesive; it has high mechanical strength, rough surface, large surface area, and high adhesion to biomass. Despite polyurethane sponge is an artificial product, it has no wastes. In this study, we tend to use Luffa sponges in combination with polyurethane sponges to work together as a hybrid media.

The objective of this study was to evaluate the performance of the integrated fixed-film activated sludge process (IFAS) packed with natural media such as Luffa sponges and artificial media such as polyurethane sponges instead of the expensive plastic media to treat the cement industrial wastewater in order to use it in restricted irrigation, kiln washing and mixing raw material of cement to form the slurry.

Materials and Methods

Preparation of modified Luffa sponges

Luffa sponges used in this study were obtained from Sharqi, Egypt. Both ends of the Luffa sponge were removed and the middle part was cut into small cylindrical pieces 2-3 cm long. To remove any suspended minerals or impurities attached to its fibers, it was immersed in distilled water for 24 h. After that Luffa was collected and dried in an oven at 140 °C for 24 h to remove any moisture content from fibers. Luffa sponge is biodegradable, so to enhance its mechanical properties and durability, Calcium carbonate (CaCO_3) provides Luffa fibers with better physic-mechanical properties (Patel and Dhanola, 2016). Luffa sponges were put in a lime solution with 30% concentration for 48 h, then dried for 24 h at 25 °C (Latinwo et al., 2010). An additional modification was performed to increase the number of bacteria in the IFAS basin by increasing the surface area. Sponges were coated by plasticized polymer as Acrylic-Styrene polymer (Dang et al., 2020). First, the Acrylic-Styrene polymer was mixed with water to form a solution, and then sponges were soaked for 1 h, Luffa sponges were dried at 25 °C for 24 h to be ready for use, as shown in Figure 1.

Table 1. Illustration of the effects of modification on the physical properties of Luffa sponges.

Parameters	Raw Luffa sponge	Modified Luffa sponge
Density (g/cm^3)	0.34	0.37
Surface area (m^2/g)	0.024	1.1

Preparation of polyurethane sponges (PU)

Polyurethane sponges were washed in distilled water and then put in an oven for 12 h. After drying sponges, PU sponges were cut into small cubic pieces with dimensions (20 x 20 x 20) mm. the density of PU sponges was $0.028 \text{ g}/\text{cm}^3$, with a BET surface area $0.85 \text{ m}^2/\text{g}$.

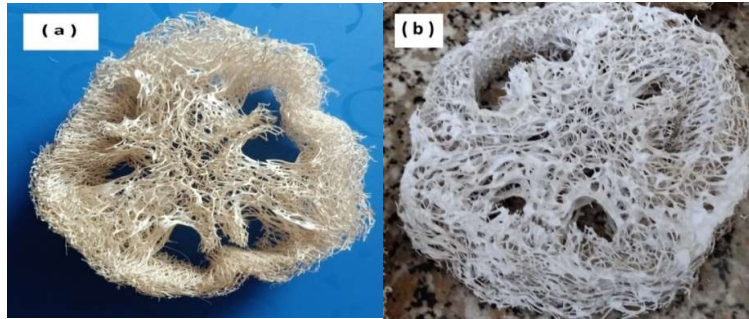


Figure 1. The difference between raw Luffa (a) and modified Luffa sponges (b).

Collecting of cement industrial wastewater samples

Cement industrial wastewater was collected from the Misr Beni-Suef cement plant in Egypt. Raw wastewater was directly filled into 4 plastic containers (25 liters for each). For each run of our experimental study, 100 liters of raw wastewater were collected and then transferred to the location of the experiment. The plastic containers were stored in a secured location at a suitable temperature ($4\text{ }^{\circ}\text{C}$) to keep their physical and chemical characteristics as uniform as possible. In order to analyze the characteristics of raw samples, all tests were performed at the national research center in Egypt.

Description of IFAS pilot experiment

This lab-scale pilot was designed as a simulation of the IFAS treatment plant. IFAS pilot consists of 3 glass basins of 45 liters volume, as shown in Figure 2. The

pilot consists of a primary sedimentation tank, IFAS aeration tank, and final settling tank located at 3 different levels in order to feed each tank by gravity through pipe connections. Air was diffused to IFAS tank by using an air blower (AQUARIUM, AP-556) that supply air to the IFAS basin at a rate of 400-480 L/h to provide the sufficient dissolved oxygen (DO) of 4 mg/L required for organic matter degradation and help bio-carriers to be suspended in the tank by providing complete mixing with wastewater. In this study, the biological treatment of cement industrial wastewater was performed with different IFAS media; each run was repeated 3 times. The first run was performed by using Luffa sponges as IFAS media, in the second run, polyurethane sponges were used. Finally, we used a combination of both media in the third run in order to compare the characteristics of each effluent to determine the most effective used IFAS media.

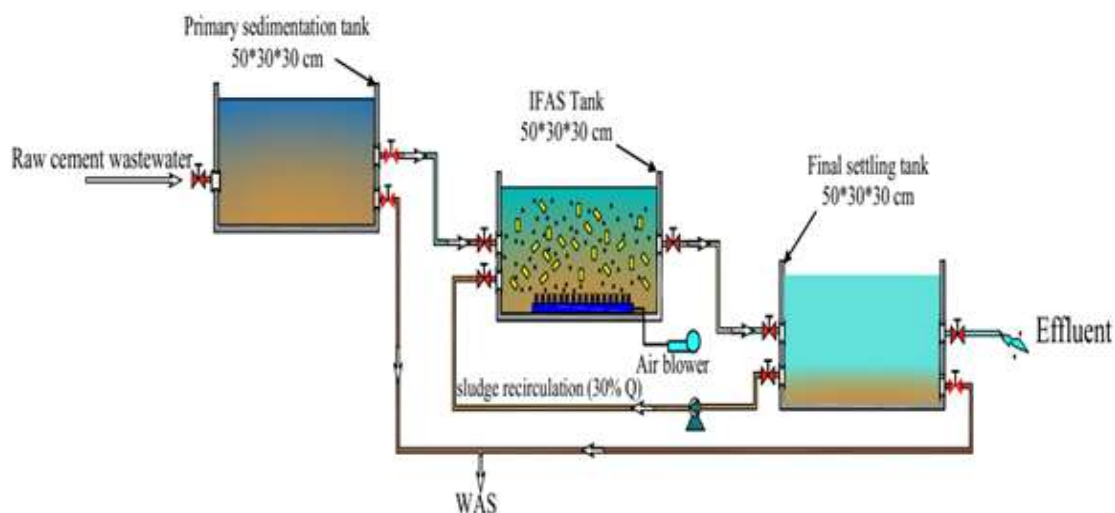


Figure 2. Scheme of IFAS pilot-scale process.

First, we adjusted the pH of raw wastewater by adding hydrogen chloride as a strong acidic to reduce the high pH of raw wastewater (9) to be suitable for biological treatment. Then, the primary sedimentation tank was fed with modified raw water taken from the cement

plant. After 3 hours, wastewater was passed under gravity to the IFAS tank by pipe connections between both tanks, prepared by different media in each run with a filling ratio of 30%. IFAS reactor was operated in November at room temperature ($24 \pm 2\text{ }^{\circ}\text{C}$). We

operated the IFAS basin at two different hydraulic retention times-HRT-(12 h, 24 h) to study the effect of the hydraulic retention time on the characteristics of the effluent. Finally, wastewater was passed to the

final settling tank in order to settle the suspended solids produced from biological treatment. All the pilot dimensions and IFAS operational parameters were illustrated in Table 2.

Table 2. The dimensions and the operational parameters of each tank of the scale pilot.

Treatment tanks	Parameters	Values
Primary sedimentation tank	Length × width × depth	0.5 × 0.3 × 0.3 m
	Wet depth (water depth)	0.25 m
	Water volume	0.0375 m ³
	Hydraulic retention time	3 h
IFAS tank	Length × width × depth	0.5 × 0.3 × 0.3 m
	Wet depth (water depth)	0.25 m
	Water volume	0.0375 m ³
	Hydraulic retention time	12 h - 24h
	Volume of media %	30%
Air blower	Air flow rate	400 - 480 L/h
Final settling tank	Length × width × depth	0.5 × 0.3 × 0.3 m
	Hydraulic retention time	2 h
	Sludge recirculation rate	30%

Chemical and physical analysis

Grab samples were collected after each step of treatment in order to determine the characteristics of the influent and effluent of each tank. Temperature (T °C) was measured every day before collecting wastewater samples. BOD, COD, TN, TP, TSS and heavy metals concentrations were analyzed at the international research center according to the disciplines in standard methods for the examination of water and wastewater (Rice et al., 2012). The density of both Luffa and PU sponges was determined according to the following equations:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

The Brunauer-Emmett-Teller (BET) surface area was calculated by measuring N₂ adsorption using an automatic surface analyzer (TriStar II 3020, Micrometrics, and USA).

Results and discussion

Raw cement industrial wastewater characteristics

Raw cement wastewater samples were collected from Misr Beni-Suef cement plant in Egypt. Raw samples were analyzed at a temperature of 22 °C. COD, BOD, TSS, TN, TP, and heavy metals concentrations are represented in Table 3.

Table 3. Characteristics of the raw cement industrial wastewater.

Parameters	Raw influent (mg/L)		
	First trail	Second trail	Third trail
pH	10 ± 0.1	9.8 ± 0.2	9.9 ± 0.1
Biological oxygen demand, BOD	322 ± 1	334 ± 2	340 ± 8
chemical oxygen demand, COD	570 ± 13	545 ± 11	556 ± 2
Total suspended solids, TSS	613 ± 7	585 ± 21	620 ± 12
Total nitrogen, TN	93 ± 1.5	91.7 ± 1.1	90.4 ± 1.1
Total phosphorous, TP	12.1 ± 0.17	12.1 ± 0.17	12.1 ± 0.17
Lead, Pb		0.01 ± 0.03	
Zinc, Zn	0.41 ± 0.02	0.48 ± 0.05	0.5 ± 0.03

Table 3 shows that the pH of cement wastewater was in the range of (9.6-10.2) which indicates the high alkalinity of cement wastewater. The pH of our raw sample was slightly higher than the overall average pH of wastewater produced from cement plants around the world (Freeda Gnana Rani et al., 2005; Ipeaiyeda et al., 2017). The increase of pH was due to high

concentrations of calcium and hydroxide carbonates and bio-carbonates found in cement wastewater. From Table 3, the COD and BOD concentrations were higher than the overall average effluent of organic compounds produced from cement plants around the world that range between (42–170) mg/L for COD and (3.1–12.2) mg/L for BOD (Ipeaiyeda et al., 2017). The

increase in COD and BOD concentrations was due to the municipal wastewater from the administrative building inside the cement campus that was mixed with industrial wastewater because the plant has a combined sewage system of both industrial and municipal wastewater. Also, the TN, TP, and TSS concentrations of our raw samples were at the range of the overall average cement wastewater effluent concentrations that vary from (64-395) mg/L, (10.5-66.6) mg/L, and (20-1590) mg/L respectively (Ipeaiyeda et al., 2017; Kumar and Thakur, 2017).

Performance of IFAS treatment

The results listed in Table 4 summarize the characteristics of wastewater effluent after IFAS treatment system packed with 3 different biomass carriers. In this experimental study, the effluent wastewater was analyzed to study the possibility of reuse cement wastewater for agriculture purposes such as fruitless irrigation. By comparing the previous results with the Egyptian Code of Practice for the Reuse of Treated Wastewater for Agricultural Purposes (ECP 501, Egyptian Code of Practice for the Reuse of Treated Wastewater for Agricultural Purposes, 2005), we found that the treated cement effluent met the Egyptian limitations regarding TSS, BOD, TN, TP, pH, and heavy metals concentrations to be used for the irrigation of wood trees and industrial oil crops.

Removal of total suspended solids (TSS)

Table 4 shows the concentration of TSS after each step of treatment during the 3 different experimental attempts. The TSS removal efficiency of the 3 attempts was 96.3%, 94.2%, and 94.6%, respectively. From TSS values in Table 4, we noticed that the concentration of TSS increased by 30% to 50% in IFAS tank by increasing the hydraulic retention time from 12 h to 24 h due to the biodegradation of organic matter by the attached and suspended microorganisms that produce a large amount of biomass in the basin, in addition to the returned sludge (RAS) from the final clarifier to IFAS tank. From the previous results, it was observed that using PU sponges as IFAS media achieved the lowest TSS removal efficiency compared to the other bio-carriers. By performing some investigations, we found that the surface area of PU sponges was 0.85 m²/g that was less than the modified Luffa surface area (1.1 m²/g), leading to a decrease of attached microorganisms that produce fewer TSS concentrations compared to Luffa sponge. Also, the low density of PU sponges was a reason to decrease the attached microorganisms because part of the surface area of sponges was out of water due to the very low density of PU sponges (0.028 g/cm³) compared to modified Luffa media (0.37 g/cm³) that made it floating on the water surface, so fewer numbers of microorganisms attached to PU surface that affect the biomass production.

Removal of heavy metals

Lead and zinc were the most common heavy metals found in cement wastewater as both zinc and lead were present in cement wastewater in high concentrations higher than allowable limits and all the other heavy metals have concentrations lower than allowable limits. These toxic metals are considered a big threat to the surrounding environment due to their toxicity to aquatic life as these metals are not able to biodegrade by biological treatment. So using absorbents such as Luffa and polyurethane sponges was our solution to remove these pollutants.

Lead removal

From Table 4, the concentration of influent lead was 0.01 ± 0.03 mg/L, then reduced to a value below 0.001 mg/L with a removal efficiency of more than 90%. We noticed that Luffa, polyurethane sponges, and the hybrid media have the same lead removal efficiency, although the absorption capacity of Luffa media for lead removal is 24.9 mg/g (Anastopoulos and Pashalidis, 2020), and up to 70.7 mg/g for polyurethane sponges (Teodosiu et al., 2014). So we conclude that the lead absorption of Luffa sponges was improved despite its low absorption capacity compared to PU sponges. This may be due to the enhanced absorption capacity of Luffa sponge after modifying its fibers by coating it with Acrylic–Styrene polymer and calcium carbonate, causing an increase in BET surface area that maximizes the Lead uptake to 170% (Anastopoulos and Pashalidis, 2020), also the hydraulic retention times in IFAS tank (12 h, 24 h) was an important factor in achieving the high absorption efficiency of Luffa sponges. HRT provided sufficient time for the highest lead uptake as it reached the equilibrium after 10 h (Anastopoulos and Pashalidis, 2020), which was the reason for the no change in Pb effluent after HRT 12 h and 24 h. Some factors are affecting the performance of PU sponges that caused the same lead removal efficiency of Luffa sponges despite the high absorption capacity of PU sponges. The Lead absorption capacity of PU sponges decreased due to high pH (8.3) in the IFAS basin because Lead removal decreased for pH >5.0 (Anastopoulos and Pashalidis, 2020); also the incomplete mixing between wastewater and PU sponges affect its absorption capacity, as the low-density, PU sponges were floated on the water surface, that reduced the BET surface area, causing a low Lead removal efficiency.

Zinc removal

Zinc removal efficiency of Luffa, polyurethane sponges and the combination between both was 51.2%, 58.3%, and 64%, respectively, as shown in Table 4. According to other studies, the Zinc uptake percentage of Luffa sponges and PU sponges was 63% (Adie et al., 2013) and >95% (Shamsi et al., 2017), respectively.

Table 4. Average concentrations of treated effluent by using different IFAS media.

Parameters*		pH	TSS	COD	BOD	TN	TP	Zinc, Zn	Lead, Pd	
		mg/L								
IFAS with Luffa media	Raw influent	10±0.1	613 ± 7	570±13	322±1	93±1.5	12.1±0.17	0.41±0.02	0.01±0.03	
	P.S (3 h)	7.6±0.3	246.7 ±12.3	371±17.7	213.7±4	70±5.5	9.6±0.2	0.32±0.03	0.0028	
	After IFAS tank	7.7±0.1	314.8±17	135±11	62±6	32.6±1	7.2±0.4	0.25±0.01	< 0.001	
	HRT-12h-	7.7±0.2	356±18	93±6	49±4.5	30±2.5	4.1±0.35	0.23±0.02	< 0.001	
	HRT-24h-	7.4±0.5	22.5±1.8	80.1±7.6	40.1±5.2	23±2	3.8±0.35	0.2 ± 0.03	< 0.001	
IFAS with PU sponges media	Raw influent	9.8±0.2	585±21	545±11	334±2	91.7±1.1	12.1±0.17	0.48±0.05	0.01±0.03	
	P.S (3 h)	7.7±0.35	240.6±11	405±8.3	230.8±5	71±1.4	9.3±0.15	0.36±0.03	0.0025	
	After IFAS tank	8.3±0.2	303±13.8	138±8.5	80±6.7	37±1.1	7.2±0.45	0.27±0.05	< 0.001	
	HRT-12h-	8.3±0.1	334.3±15.2	91±8	55.4±8	36±3	4.4±0.3	0.27±0.03	< 0.001	
	HRT-24h-	8.2±0.25	33.7±3.9	85±7	46±5.2	29±2.4	4.1±0.3	0.2 ± 0.03	< 0.001	
IFAS with hybrid media	Raw influent	9.9±0.1	620 ± 12	556±2	340±8	90.4±1.1	12.1±0.17	0.5 ± 0.03	0.01±0.03	
	P.S (3 h)	7.6±0.25	243±14	360.5±15	213±7	69±1.8	9.7±0.3	0.38±0.03	0.0031	
	After IFAS tank	8.2±0.3	320.7±16.9	106±4.8	55±3.8	39±0.7	7±0.4	0.23±0.01	< 0.001	
	HRT-12h-	8.2±0.2	364.5±20	78±4.6	36±3	28±5.6	3.9±0.3	0.22±0.03	< 0.001	
	HRT-24h-	8.2±0.2	26.8±2.8	68±5	31.4±2.7	21.7±2	3.7±0.3	0.18 ±0.02	< 0.001	
Specifications		6.5-8.4	Treatment Permitted for fruitless irrigation Use (wood tress-industrial oil crops)						5	5
		6-9	250	---	400	40	10	Limitations of treated water to drain to sewage systems		
			60	100	60	40	10	1		

*HRT = hydraulic retention time P.S= primary sedimentation

By comparing our results with the others. We noticed that all the 3 attempts were not effective in Zinc removal. Zinc absorption is a function of the solution pH. In the IFAS tank packed with Luffa sponges, the pH was 7.7, and the investigations showed that Luffa sponges are effective for Zn removal at pH (2-6), and Luffa's absorption capacity for Zn decreased if pH >6 (Nouacer et al., 2017). Also, the PU sponge was not effective for Zn removal because the experiment was performed at pH = 8.3, and the optimum pH for Zn uptake in the case of using PU sponges was 8, so it achieved its maximum absorption at pH = 8 then gradually decreased (Ahmad and Ahmed, 2008).

Effect of each media on organic matter removal performance

The COD and BOD removal of the IFAS process using different media is presented in Table 4. It was observed that the combination of Luffa and PU sponges was the most effective for organic matter disposal with removal efficiency up to 87.8% COD and 90.7% BOD, respectively, because it has a large BET surface area that increased the attached biomass to the media. So an effective removal of organic compounds was achieved. Luffa and PU sponges were also effective for COD and BOD removal, but not on the same level of efficiency. The COD and BOD removal efficiency of Luffa media were 86% and 88%, respectively. The performance of Luffa sponges in our experimental study was not perfect enough as it was lower than COD removal efficiency of other studies that exceeded 90% (Ruiz-Marín et al., 2009; Dang et al., 2020). This variation in COD removal was due to the low hydraulic retention time (24 h) performed in our experimental study. In these studies, HRT reached 24 days that allowed more time for bacteria to grow to lead to a higher organic matter removal. In the case of using polyurethane sponges as IFAS media, COD and BOD removal efficiency decreased to 84.4% and 86.2%, respectively. COD and BOD removal were similar to other studies that used PU sponges as IFAS media that achieved COD removal efficiency of 80%- 86% (Chu et al., 2014). Luffa sponge was more effective in COD and BOD removal than PU sponges. The control parameter that caused the difference in removal efficiency was the BET surface area of each media. The BET surface area of modified Luffa and PU sponges was 1.1 and 0.85 m²/g, respectively that increased the yield of attached biomass to Luffa sponge compared to PU sponges. Also, the attached biomass to PU sponges may be less than Luffa sponges due to the repulsion between PU sponges and the bacteria as it has a higher negative surface charge similar to the surface of bacteria cells (Mahendran et al., 2012; Chu et al., 2014). Luffa sponges have a higher biomass absorption capacity than PU sponges because it composes of organic fibers with some types of nutrients that help the microorganisms to grow, leading to higher biomass concentration. The density of PU media may be another reason for the low COD and BOD removal efficiency; the modified Luffa

sponge density was 0.37 g/cm³ which made it suspended in the basin and fully mixed with wastewater. PU sponge density was 0.028 g/cm³ that caused it to float on water and a portion of its surface area was out of water that makes it without any role in the biodegradation of organic matter, as shown in Figure 3. Low-density PU sponges caused less attached biomass by 30% compared to immersed media (Chu et al., 2014).

Removal of nitrogen compounds

In our IFAS scale-pilot, nitrification and denitrification were performed at the same basin without the need for a separated aerobic and anoxic tank in order to study the performance of using different media for nitrogen removal. Luffa and PU sponges are porous media, so anoxic, aerobic, and anaerobic zones were formed at the outer and inner layers of Luffa and PU sponges due to the oxygen transfer limitation. The nitrogen removal performance of Luffa sponges, PU sponges, and the mixed media is presented in Table 4. In the case of using modified Luffa as an IFAS media, The average TN removal efficiency was 75.3% that coincide with a TN removal efficiency from 71% to 78% achieved by other researchers (Li et al., 2019; Dang et al., 2020). During IFAS packed with PU sponges, the TN removal efficiency was 68.4%. Some researchers in (Chu et al., 2014) reported a low TN removal ranged from 25% to 45% while using PU sponges as IFAS media with a filling ratio of 25% which was lower than our achieved efficiency, it may be due to the high filling ratio of PU sponges (30%) performed in the IFAS pilot that enhanced the nitrification and dis-nitrification process by increasing the nitrifying growth and providing anoxic zones within the layer of PU media. So using modified Luffa sponge achieves better TN removal than PU sponges, as modified Luffa has a BET surface area (1.1 m²/g) more than PU sponges (0.85 m²/g), which allowed more attached slow-growing nitrifying bacteria to remain in the IFAS basin, also large surface area allows the formation of more anoxic zones within media which stimulates de-nitrification conditions. As expected, the combination between Luffa and PU sponges was the most effective media with a removal efficiency of 75.9%, as it provides a large surface area that help growth of attached biomass necessary for nitrogen removal.

Removal of phosphorus compounds

Total phosphorous (TP) concentrations during our experiment are shown in Table 4. The stage of the primary sedimentation was able to reduce TP concentration by an average removal efficiency of 21.1% because part of phosphorous compounds is insoluble and particulate. TP removal efficiency of Luffa, PU sponges, and the combination between both IFAS media was 68.5%, 66.1%, and 69.4%, respectively that observed to be very close despite using different IFAS media on each run. By reviewing

other studies, we noticed that IFAS systems using separate anoxic zone achieved TP removal up to 80% (Shamsi et al., 2017; Mannina et al., 2020), so our IFAS pilot that depends on a single basin for nutrients removal was not effective in TP removal. Each media used in the present study consists of layers that create aerobic zones at the outer layer and anaerobic zones at the deep layer due to non-perfect dissolved oxygen distribution in the basin. These anaerobic zones were not sufficient for polyphosphate accumulating organism (PAO) populations. So poor active PAOs are attached to biomass that affects the phosphorous release.

Also, this study depends on the biomass attached to IFAS media for nitrogen and phosphorous removal, which may be the reason for insufficient oxygen in the basin due to the competition between nitrifying bacteria and PAOs which abstract phosphorous up-take. The influent wastewater was with a low C/N ratio, so it has limited organic carbon, not enough for denitrifying and the PAOs organisms, so it affects the TP removal. The removal efficiencies of the used IFAS media were not up to expectation if we depend on a single IFAS reactor. In order to improve TP removal, PAOs bacteria must be enriched by improving the anaerobic and aerobic zones.

Conclusion

IFAS technology is a very effective wastewater treatment technology as it achieves very high removal efficiencies of all types of pollutants found in wastewater. This experimental study proved that IFAS technology is very effective in treating industrial cement wastewater. Also, using bio-carriers such as Luffa sponges and polyurethane sponges instead of plastic media gives very satisfied COD, BOD, and TSS removal efficiency after performing some chemical modification of Luffa sponge's fibers in order to increase its durability and mechanical strength properties. From this experimental study, IFAS technology reduced the physiochemical concentrations of cement wastewater below the Egyptian code limitation for reuse in restricted irrigation purposes.

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