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Employing Watermelon rind, Polyurethane Sponges, and Cotton fibers as Bio-carriers

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Abstract - *Water scarcity in Egypt is a critical issue that threats all the life fields such as industry and agriculture sectors. So, searching for alternative water resources was the key solution by depending on treating dairy wastewater in order to provide sufficient treated water enough to reuse in other fields. Integrated fixed film activated sludge process (IFAS) was employed as a biological treatment process. A laboratory pilot was established as a simulation of the biological treatment process. The laboratory pilot consists of primary sedimentation tank, aeration tank, and final settling tank with dimensions of 50 × 25× 25 cm for each. Three bio-carriers were used as IFAS Media with different filling ratio in order to achieve COD, BOD, TN, and TP removal efficiency. Watermelon rind was used in the first experimental trial, then Polyurethane sponges in the second experimental trial, and Cotton fibers in the third experimental trial. After analyzing the physicochemical characteristics of dairy wastewater samples, it was clear that Cotton fibers was the most effective in removing BOD, BOD, TN, and TP concentrations with removal efficiency of 88.35%, 88.3%, 76 %, and 69.3% respectively.*

Keywords – *Integrated fixed film activated sludge; bio-carrier; watermelon; Polyurethane sponges; Cotton fibers*
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1. Introduction

Similar to many countries all over the world, Egypt is among these countries that suffer with water scarcity. Water scarcity is considered the critical issue of the modern world due to its effect on various life aspects such as agriculture, human requirement, and industry. As a result, researchers in Egypt began to search for alternative water resources in order to use it in other fields. So, wastewater treatment was the golden key in order to provide large amounts of water that has a proper quality to reuse it in various fields especially agriculture field.

Researchers in Egypt paid a lot of attention on wastewater generated from food industry. As, Food industry in Egypt produces large amount of wastewater that could be reused after proper treatment process. In addition to the large amount of food industry wastewater, this type of wastewater contains various types of pollutants that have negative effect to the environment. So, treatment of this type of industry especially dairy wastewater was a step among many steps on the way to provide sufficient amount of treated wastewater enough for agriculture field.

Dairy industry depends on converting milk into products. This process generated large amount of wastewater that is loaded with many types of pollutants such as fats, proteins, organic matter, methane, nitrogen, and phosphorous. Thousands of wastewater was produced from dairy industry as one liter of milk produces about 7 to liter of wastewater that is considered a real threat to the aquatic life (Verma *et al.*, 2012).

As a result of the high polluted wastewater, searching for an effective wastewater treatment technology became a necessary aim. Many wastewater treatments was employed to reduce the pollutants concentration that found in dairy wastewater effluent such as activated sludge process (ASP), membrane biofilm reactors (MBRs) (Naghizadeh *et al.*, 2011), effective microorganisms technology, and moving bed biofilm reactors (MBBRs) (Luo *et al.*, 2014).

Besides the previous wastewater treatment technologies, integrated fixed film activated sludge (IFAS) is a promising treatment methods that can be used for dairy wastewater treatment due to its remarkable advantages. IFAS depend on bio-carriers of different materials in order to allow the biomass in the IFAS basin to attach to the surface of the bio-carriers that leads to an increase in the mixed liquor suspended solids (MLSS). Increasing MLSS allows an improvement in the removal efficiency of organic matter and nutrients concentrations. Also, depending on IFAS as a dairy wastewater treatment can help in reducing the concentrations costs as it provides a less footprint compared to the other wastewater treatment technologies. Also, IFAS method allows the nitrification and de-nitrifications process to perform in the same basin without the need of using an additional anoxic tank (Metcalf, E.; Abu-Orf, M.; Bowden, G.; Burton, F.L.; Pfrang,W.; Stensel, H.D.; Tchobanoglous, G.; Tsuchihashi, 2014; DROSTE, Ronald L.; GEHR, 2018).

In order to apply an effective IFAS process, choosing the proper bio-carrier is a necessary step. As bio-carrier is considered the most important factor that control the removal of the pollutants. Several studies used many types of IFAS media such as plastic media, Luffa media, zeolite, gravel, and cotton (Dang *et al.*, 2020). By controlling the shape and the size of the biomass carriers, it is expected to achieve a high removal efficiency of wastewater pollutants.

In this research paper, a laboratory study was performed on dairy wastewater using IFAS technology by employing several biomass carriers such as watermelon rind, cotton, and polyurethane sponges as alternative of the high cost plastic media as a trial to reduce the organic matter concentrations to allowable limits in order to reuse it for agriculture purposes.

2. Materials and methods

2.1 Collection of raw wastewater samples

Dairy wastewater was collected from Al-Albour factory located in Egypt. Samples were collected and put in two plastic containers with 50 liters in volume for each. After that, plastic container were transferred to the laboratory and stored at 4°C in order to avoid any change in it physicochemical characteristics.

2.2 Preparation of watermelon rind as IFAS bio-carrier

Watermelon rind was dried in an oven at temperature of 140°C. Then it was cut into small pieces of 3 cm as shown in Figure (1). By using a sharp tool, watermelon rind was holed in order to make an interior area inside watermelon rind. Water melon rind was soaked in $CaCO_3$ solution for 24 hours in order to increase the durability of the watermelon fibers.

Figure 1. Watermelon rind

2.3 Preparation of Cotton as IFAS bio-carriers

Cotton was immersed in distilled water in order to remove any impurities that attached to cotton's fibers as shown in Figure (2).

Figure 2. Cotton bio-carriers

2.4 Perpetration of polyurethane sponges as IFAS sponges

Polyurethane sponges were cut into small pieces of 3 to 4 cm with dimensions of 25×25× 25 cm. in order to use the polyurethane sponges as IFAS bio-carrier, polyurethane sponges were soaked into distilled water with 20°C in order to remove any suspended impurities attached to the polyurethane sponges. Then, PU sponges were dried in an oven at 140°C as shown in Figure (3).

Figure 3. Polyurethane sponges

2.5 Description of the laboratory pilot

In this study, a laboratory pilot was established in order to simulate the integrated fixed film activated sludge process. This laboratory pilot consists of three glass tanks with dimensions of 50 ×25× 25 cm. The experimental trials were carried as following:

1. Raw wastewater was fed into the primary sedimentation tank with hydraulic retention time of three hours.
2. At the beginning of the experimental trial, the pH of the raw dairy wastewater was modified in order to decrease the pH to be suitable for the aeration process.
3. Then, dairy wastewater was passed under gravity through plastic pipes to the IFAS tank that equipped with an air blower with three outlets that is necessary to supply dissolved oxygen to the IFAS tank.
4. The IFAS bio-carriers were put into the IFAS tank with a specific filling ratio as shown in Table II.
5. Dairy wastewater was remained in the IFAS tank for a hydraulic retention time of 24 hours
6. After HRT of 24 hours, dairy wastewater was passed into the final settling tank to remove any suspended solids produced from the IFAS tank.

This experimental study was performed by using three IFAS bio-carrier as following:

- First experimental Trial: Watermelon rind
- Second experimental Trial: Cotton Fibers

Third experimental Trial: Polyurethane sponges

Table 1. Operational Parameters of the experimental study

Tank	Parameter	Value
Primary Sedimentation tank	water volume	300 liters
	Length × width × depth	50 × 25× 25 cm
	Hydraulic retention time	3 hours
IFAS tank	Length × width × depth	50 × 25× 25 cm
	water volume	300 liters
	Hydraulic retention time	24 hours
Air blower	Type	SPT500
	Rate of flow	350 L/h
Final settling tank	water volume	300 liters
	Length × width × depth	50 × 25× 25 cm
	Hydraulic retention time	3 hours
	Sludge recirculation rate	25 %

Table 2. Filling ratio of the IFAS bio-carriers

IFAS bio-carrier	Filling Ratio (%)
Watermelon rind	35 %
Cotton Fibers	30 %
Polyurethane sponges	40 %

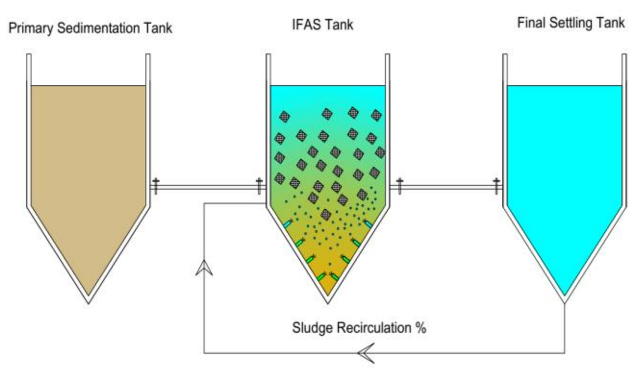

Figure 4. IFAS laboratory pilot

3. Results and discussion

3.1 Dairy wastewater characteristics

Table 3 illustrates the concentrations of COD, BOD, TSS, TN, and TP of the raw dairy wastewater after analyzing it at the national research center in Cairo.

Table 3. Physicochemical properties of raw dairy wastewater

Parameters	Raw 1	Raw 2	Raw 3	Average
pH	7.4	6.1	7.0	6.9
Total suspended solids, TSS	792.0	650.9	785.4	742.8
Biological oxygen demand, BOD	1441.0	1198.1	1415.7	1351.6
Chemical oxygen demand, COD	2332.0	2150.4	2534.4	2338.9
Total nitrogen, TN	253.0	208.3	247.5	236.3
Total phosphorous, TP	45.1	46.1	44.0	45.1

From Table 3, it was clear that dairy wastewater is loaded with high concentrations of organic matter and nutrients (Nitrogen and phosphorous). The average pH of the raw dairy wastewater is 6.9 that tend to be an acid. This acidic state was due to the presence of lactose that is transferred into lactic acid causing a decrease in pH value. The pH of dairy wastewater was similar to the pH of another dairy wastewater samples discussed by the previous studies. These studies reported that the overall average pH value was between 4.1 to 8.8 (Al-Wasify, Ali and Hamed, 2017). The average COD and BOD values of raw dairy wastewater were 2338.9 mg/L and 1351.6 mg/L. This high concentration of organic matter was due to the presence of fats and proteins that increase the organic matter concentration. The previous COD and BOD concentrations of raw dairy wastewater were closer to the average overall values of COD and BOD that was at the range of 1200 to 1800 mg/l and1900 to 2700 mg/l, respectively.

3.2 Result of Experimental Trials

Table 4. Physicochemical characteristics of dairy wastewater (Experimental Trial 1)

Experimental Trial	Parameters	PH	TSS	BOD	COD	TN	TP
Watermelon rind	RAW	7.4	792.0	1441.0	2332.0	253.0	45.1
	PS	7.4	318.7	956.3	1517.8	190.4	35.8
	24 HR	8.2	460.0	219.3	380.5	81.6	15.3
	FS	8.2	29.1	179.5	327.7	62.6	14.2

Table 5. Physicochemical characteristics of dairy wastewater (Experimental Trial 2)

Experimental Trial	Parameters	PH	TSS	BOD	COD	TN	TP
Polyurethane sponges	RAW	6.1	650.9	1198.1	2150.4	208.3	46.1
	PS	6.2	267.7	827.9	1598.0	161.3	35.4
	24 HR	7.6	372.0	198.7	359.1	81.8	16.8
	FS	7.5	37.5	165.0	335.4	65.9	15.6

Table 6. Physicochemical characteristics of dairy wastewater (Experimental Trial 3)

Experimental Trial	Parameters	PH	TSS	BOD	COD	TN	TP
Cotton Fibers	RAW	7.0	785.4	1415.7	2534.4	247.5	44.0
	PS	7.0	307.8	886.9	1934.4	188.9	35.3
	24 HR	7.1	461.7	149.9	320.2	76.7	14.2
	FS	7.1	33.9	130.7	297.4	59.4	13.5

3.3 Performance of watermelon rind, PU sponges, and Cotton as IFAS bio-carriers

3.3.1 COD and BOD removal

3.3.1.1 Watermelon rind

From Table 4, the concentration of BOD and COD in the raw dairy wastewater sample was 1441 mg/L and 2332 mg/L, respectively. Then, it decreased after the primary sedimentation tank (Hydraulic retention time = 3 hours) to 956.3 mg/L and 1517.8 mg/L, respectively. This decrease in BOD and COD concentrations was due to the presence of suspended organic containments (not soluble) that had been settled under gravity force (Metcalf and Eddy, 2003). After hydraulic retention time of 24 hours in the aeration basin, the BOD and COD concentrations were decreased to 219.3 mg/L and 380.5 mg/L by removal efficiency of 84.7% and 83.68%, respectively. After hydraulic retention time of 3 hours in the final settling tank, the BOD and COD concentrations were decreased to 179.5 mg/L and 327.7 mg/L by removal efficiency of 87.5% and 85.9%, respectively.

3.3.1.2 Polyurethane sponges

From Table 5, the concentration of BOD and COD in the raw dairy wastewater sample was 1198.1 mg/L and 2150.4 mg/L, respectively. Then, it decreased after the primary sedimentation tank (Hydraulic retention time = 3 hours) to 827.9 mg/L and 1598 mg/L, respectively. This decrease in BOD and COD concentrations was due to the presence of suspended organic containments (not soluble) that had been settled under gravity force (Metcalf and Eddy, 2003). After hydraulic retention time of 24 hours in the aeration basin, the BOD and COD concentrations were decreased to 198.7 mg/L and 359.1 mg/L by removal efficiency of 83.4% and 83.3%, respectively. After hydraulic retention time of 3 hours in the final settling tank, the BOD and COD concentrations were decreased to 165 mg/L and 335.4 mg/L by removal efficiency of 86.23% and 84.4%, respectively.

3.3.1.3 Cotton fibers

From Table 6, the concentration of BOD and COD in the raw dairy wastewater sample was 1415.7 mg/L and 2534.4 mg/L, respectively. Then, it decreased after the primary sedimentation tank (Hydraulic retention time = 3 hours) to 886.9 mg/L and 1934.4 mg/L, respectively. This decrease in BOD and COD concentrations was due to the presence of suspended organic containments (not soluble) that had been settled under gravity force (Metcalf and Eddy, 2003). After hydraulic retention time of 24 hours in the aeration basin, the BOD and COD concentrations were decreased to 149.9 mg/L and 320.2 mg/L by removal efficiency of 89.4 % and 87.4%, respectively. After hydraulic retention time of 3 hours in the final settling tank, the BOD and COD concentrations were decreased to 165 mg/L and 297.4 mg/L by removal efficiency of 88.35% and 88.3%, respectively.

3.3.2 Performance of each bio-carriers for the COD and BOD removal

It was clear that, cotton was the most effective IFAS bio-carrier among the three used bio-carriers in this laboratory pilot with BOD and COD removal efficiency of 88.35% and 88.3%, respectively. The control parameter that affects the organic matter removal was the surface area of each bio-carrier and the void ratio. By increasing the surface area, the more biomass attached to the fibers of the bio-carrier that causing a high removal efficiency of organic matter containment. From comparing the previous results, it was clear that cotton fibers as IFAS bio-carriers was more effective compared to the other bio-carriers in COD and BOD removal as shown in Figure (5).

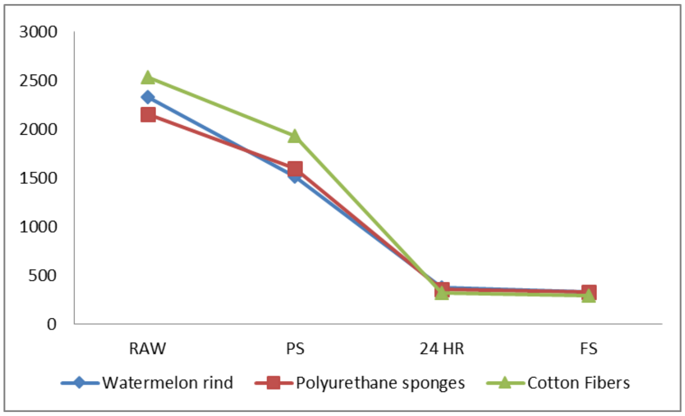

Figure 5. Performance of each media for COD and BOD removal

3.3.3 Total Nitrogen and Total Phosphorous removal

From Table 4, watermelon was able to decrease the TN and TP concentrations from 253 mg/L to 62.6 mg/L with removal efficiency of 75.3%, and from 45.1 mg/L to 14.2 mg/L with removal efficiency of 68.5%, respectively.

From Table 5, polyurethane sponges was able to decrease the TN and TP concentrations from 208.3 mg/L to 65.9 mg/L with removal efficiency of 68.4%, and from 46.1 mg/L to 15.6 mg/L with removal efficiency of 66.2%, respectively.

From Table 6, Cotton fibers was able to decrease the TN and TP concentrations from 247.5 mg/L to 59.4 mg/L with removal efficiency of 76 %, and from 44 mg/L to 13.5 mg/L with removal efficiency of 69.3%, respectively.

3.3.4 Performance of each bio-carrier for the Total Nitrogen and Total Phosphorous removal

By comparing the TN and TP removal efficiency of the three bio-carriers, it was observed that Cotton fibers were the most effective in TN and TP removal that was due to the high surface area of Cotton fibers that allow to more biomass to attach to the fibers for more time that is enough for the nitrifying process. Also, there were more voids and inner zones inside the cotton fibers that create anoxic zones. These anoxic zones create anaerobic zones that allow the de-nitrification process to take place inside the same aeration basin. Also, these inner zones create anoxic zones that help to increase the growth of polyphosphate accumulating organism (PAO) populations that increase the phosphorous removal (Zamani, 2017; Mannina et al., 2020). Figure (6) illustrates a comparison between each bio-carrier for TN and TP removal.

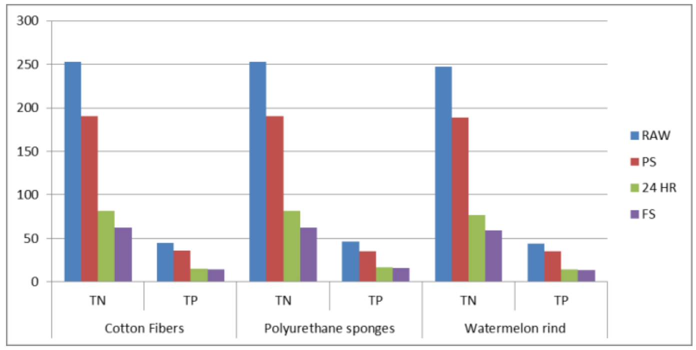

Figure 6. Comparison between each bio-carrier for TN and TP removal

4. Conclusion

Dairy wastewater is classified as one of the most polluted industrial wastewater that is considered as an actual threat to the environment and aquatic life. In order to reuse the dairy wastewater again and be safe to disposal, integrated fixed film activated sludge packed with three different IFAS bio-carriers was employed as a biological treatment process. Cotton fibers, polyurethane sponges, and watermelon rind were used as IFAS bio-carriers for achieving a high COD, BOD, TN, and TP removal efficiency. Cotton fibers were the most effective bio-carriers compared to the other bio-carriers.

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