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Assessing of Low Cost Media in Removal of Organic and Inorganic Matters from Wastewater Using Aerated Modified Trickling Filter

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Abstract— *Egypt is currently facing a major problem to provide water suitable for agriculture as a result of the growing shortage of water received from upstream countries. Nowadays, many governorates in Egypt are rapidly growing like Cairo, Alexandria, etc.; these governorates suffer from various problems regarding the availability of potable water for human usage. As a result, we need to reduce the amount of potable water used in irrigation and substituting it with well treated wastewater. Implementing economical and effective wastewater treatment techniques is an urgent requirement. The main objective of this research is to assess the technique performance of the aerated modified trickling filter (AMTF) which was monitored for several months using different multimedia and the analysis focused on chemical oxygen demand (COD), biological oxygen demand (BOD) and total suspended solid (TSS) of the influent and effluent wastewater. A pilot plant was designed, erected and operated in Zenien wastewater treatment plant, Giza Egypt. The media named sandwich media consists of non-woven polyester, date palm fiber and hair buckles with sponges. The results showed that the sandwich media was effective in TSS removal with efficiency reaching 94.6 %, while the removal of COD reached 86 % and BOD removal reached 85 %.*

Keywords — aerated modified trickling filter (AMTF); chemical oxygen demand (COD); biological oxygen demand (BOD); total suspended solid (TSS).

1. INTRODUCTION

The trickling filters with rock packing have been used for more than a hundred years in wastewater treatment. The first trickling filter was placed in operation in 1893; the modern trickling filters have a bed media of highly permeable media and operate on continuous flow. The classifications of trickling filters depend on the hydraulic and organic load [1]. Usually the influent is applied at the top of the media through the distributor arms or another distribution system. The underdrain system used to collect the effluent from the trickling filter also it is important for air circulation to keep the aerobic condition during the treatment, which is provided either by natural draft or blowers, the collected effluent settled in sedimentation tank to collect the sloughing suspended solids, then return portion –or no- to dilute the strength of the incoming wastewater and to keep the wetting of the biological slime layer moist [2].

Excess growths of microorganisms slough from the media. This would cause high levels of BOD and suspended solids in the plant effluent if not removed in the sedimentation tank. As in the case of the activated sludge process, this sedimentation basin is referred to as a secondary clarifier. Unlike the activated sludge process, the solids are not returned to the attached growth process. They are collected and removed for processing and disposal [3].

The micro-filtration process has pore sizes of approximately (0.03 to 10) microns and operating pressure of (15-60) psi. It can remove contaminants such as silt, clay, sand, and some of the bacteria. Ultra-filtration process has pore sizes of approximately (0.002 to 0.1) microns and operating pressure of (30-100) psi and can remove contaminants such as bacteria and some virus's species. The nano-filtration process has nominal pore sizes of approximately (0.001) microns and operating pressure of (90-150) psi and can remove all contaminants of bacteria, viruses, and human materials. The reverse-osmosis process has nominal pore sizes of approximately (0.0001) microns and high operating pressures. It can remove nearly all contaminants such as organic, inorganic substances, pesticides, bacteria, and viruses [4].

There is a lot of media used as filter packing media in trickling filters such as are stones (crushed limestone and granite), ceramic material, treated wood, hard coal, or plastic media. Some factors specify the suitability of the media, such as specific surface area, void space, unit weight, media configuration and size, durability, and cost. The most suitable media must have a high specific surface area for microbial attachment and growth, low cost, the percentage of void space must be high to minimize the clogging and allow good air recirculation [5].

The new attached growth sponge tray bioreactor (STB) was evaluated at various operating conditions for removing organics and nutrients from primary treated sewage effluent. This STB was also assessed when using as a pre-treatment before micro-filtration

(MF) for reducing membrane fouling. At a short hydraulic retention time (HRT) of 40 min, the STB remove up to 92 % of COD and 40 – 56 % of TKN and Phosphorus at an organic loading rate (OLR) of 2.4 kg COD/m³ sponge day. This OLR is the best for the STB as compared to the OLRs of 0.6, 1.2, and 3.6 kg COD/m³ sponge day. At 28 ml/min of flow velocity (FV), STB achieved the highest efficiencies with 92 % of COD, 87.4 % of Phosphorus, and 54.8 % of TKN removal. Finally, at the optimal OLR and FV, the STB could remove around 90 % of organic and nutrient; significantly reduce membrane fouling with HRT of only 120 min [6].

A porous sheet which is made of the parallel, cross, or randomly laid webs of long fibers bonded together mechanically by applying heat or pressure. This sheet works as a barrier for separating impurities from liquids [7]. Fabric media characteristics as a filter media depend on the weight of the material, thickness, water, and air permeability and non-woven fabrics have higher permeability and more pores for the unit area. Therefore, non-woven materials are widely used as separation media which have high filtration efficiency, temperature resistance, and lower in the cost. Mesh filtration bio-reactor (MFBR) was tested using nylon mesh as a filter media with 100-micron pore size and obtained effluent BOD under 5 mg/l and TSS under 1.5 mg/l as two weeks of operation till the filter clogging [8].

The non-woven module of polypropylene fabric fixed on the spool at based filtration device for treating wastewater obtained removal efficiency of about 50 % for BOD and 70 % for TSS [9]. The non-woven module was installed in membrane bioreactors to treat wastewater. Non-woven materials gave low filtration resistance compared to the micro-porous membrane and obtained effluent COD under 60 mg/l and TSS under 10 mg/l [10]. A unit equipped with non-woven fabric and oyster-zeolite submerged in activated sludge bioreactor obtained removal efficiency of about 94 % for COD while having low removal efficiencies of nitrogen and phosphorous [11]. Three different fabric materials (Nylon, Polyester, and Acrylate) were tested as separation media for the MBR unit for treating municipal wastewater and obtained removal efficiency of about (93 - 95 %) for COD, (99 %) for TSS and (89 - 94 %) for TKN [12]. Various types of fabric materials were tested at different operating conditions on a filtration unit using synthetic wastewater. Nonwoven fabrics were found to be promising as separation media for the wastewater and obtained removal efficiency of about (83 - 95 %) for COD and (87 - 94 %) for TSS [13].

2. Material and method

The experimental study plan was performed to investigate advanced filtration by using aerated modified trickling filter (AMTF) and multi-media (sandwich media). The pilot plant was designed and installed in Zenien Wastewater Treatment Plant, Giza Egypt. The pilot plant is designed to work continuously 24 hours per day during April 2018 till to December 2019.

2.1 Pilot Plant Description

A continuous flow pilot plant was designed as an advanced filtration system to serve the experimental program and objectives of this research. The pilot scale plant designed was as illustrated in Fig. 1.

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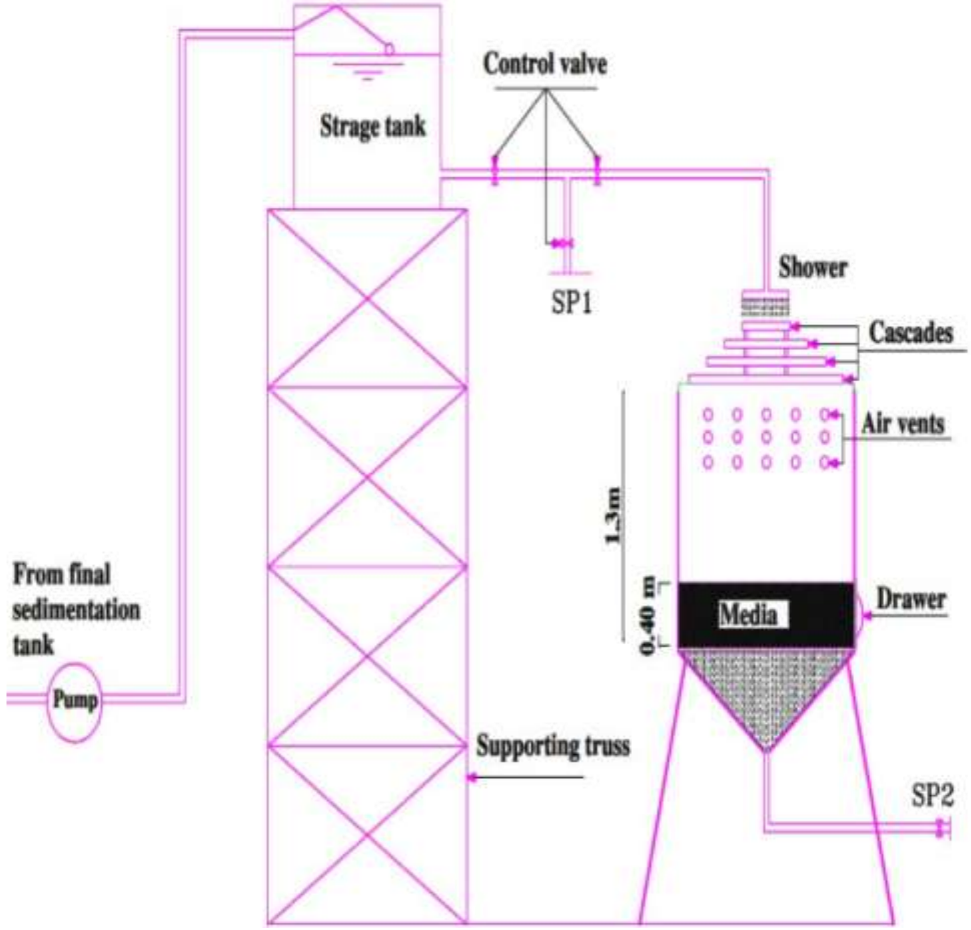

Fig. 1. *Schematic diagram of Pilot Plant*

The pilot plant consists of two parts as follows: -

- Part one consists of four cascades with different sizes (25*25), (30*30), (35*35) and (40*40) cm. The space between each cascade is 10 cm and made of PVC sheets with thickness 6 mm.
- Part two consists of the filter unit made of insulated sheet plates with dimensions (50*50*220), the filter media layer is placed in a drawer box at a height of 90 cm from the ground, while stairs have circular slots on the bottom to drain filtered water. Down the drawer, there is a cone shaped treated wastewater collection unit for subsequent disposal.

2.2 Filter Media

Based on the literature review and the previous researches, Non-woven fabric materials, sponge put in hair buckles, palm fiber, sand and light weight bricks were found to be effective in the treatment process of wastewater in small communities.

2.2.1 Non-Woven Polyester

The filter material is non-woven polyester 800 gm/m², with thickness of 1.5 cm, and a rate of clean water permeability of 3.03 l/m²/sec with a 1.5 meter of operational water head.

2.2.2 Sponge

Pieces of sponge with dimension (30mm*30mm*70mm), these were put in hair buckles with diameter 25 mm and length 70mm, void ratio 82.8% and water wetted after 2 seconds from lifting from water is 24.92%, according to the experimental test.

2.2.3 Date Palm Fiber

The physical properties of date palm fiber are as shown in Table 1.

Table 1: The Physical Properties of Date palm Fiber

Physical Properties	Date palm
Density (gm/cm^3)	0.9: 1.2
Length (mm)	0.1:1
Diameter (mm)	100: 1000
Specific modulus (approx.)	7
Thermal conductivity (W/m K)	0.083

2.3 Wastewater Sampling

Influent wastewater samples to the experimental pilot plant were collected from the effluent of secondary treatment of Zenien Wastewater Treatment Plant in Giza-Egypt and collected samples from the effluent of pilot plant. All experiments and analysis of wastewater samples were carried out at Zenien Wastewater Treatment Plant laboratory.

Samples were normally daily collected on a routine basis between 10 a.m. and 12 p.m. and transferred to the Zenien laboratory at once after collection for analysis.

2.4 Wastewater Analysis

The following characteristics were analyzed for both wastewater influent and treated effluent from the experimental study pilot plant. The parameters BOD, COD and TSS were measured for all samples during the experimental work. The analyses were carried out according to the Standard Methods for Water and Wastewater Examination (APHA- AWWA – WPCE, 19th Edition, (1999)).

2.5 Study Program

The study was carried out with certain media type and depth and also flow rate to be applied for the AMTF to be a low-cost technique for advanced wastewater treatment. The experimental work is illustrated in Table 2.

Table 2: the work paln

Operating and Monitored Parameters	Work Plan		
	Run (1)	Run (2)	Run (3)
Q (m^3/d)	5	5	5
Thickness of Media (cm)	8	16	30
Hydraulic Loading Rate ($m^3/m^2/d$)	20	20	20
COD	√	√	√
BOD	√	√	√
TSS	√	√	√
pH	√	√	√
Temperature	√	√	√

3. Results and Discussion

Experimental work was operated in three runs as follows

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3.1 Run One

This run was operated at a constant head of water 1 m, flow rate 5 m³/d, depth of media 8 cm. The system showed slight improvement in TSS, COD and BOD. The system started to deteriorate after 10 days of operation due to the appearance of a hole in the media. The results show influent, effluent and percentage removal of TSS, COD and BOD in the following figure.

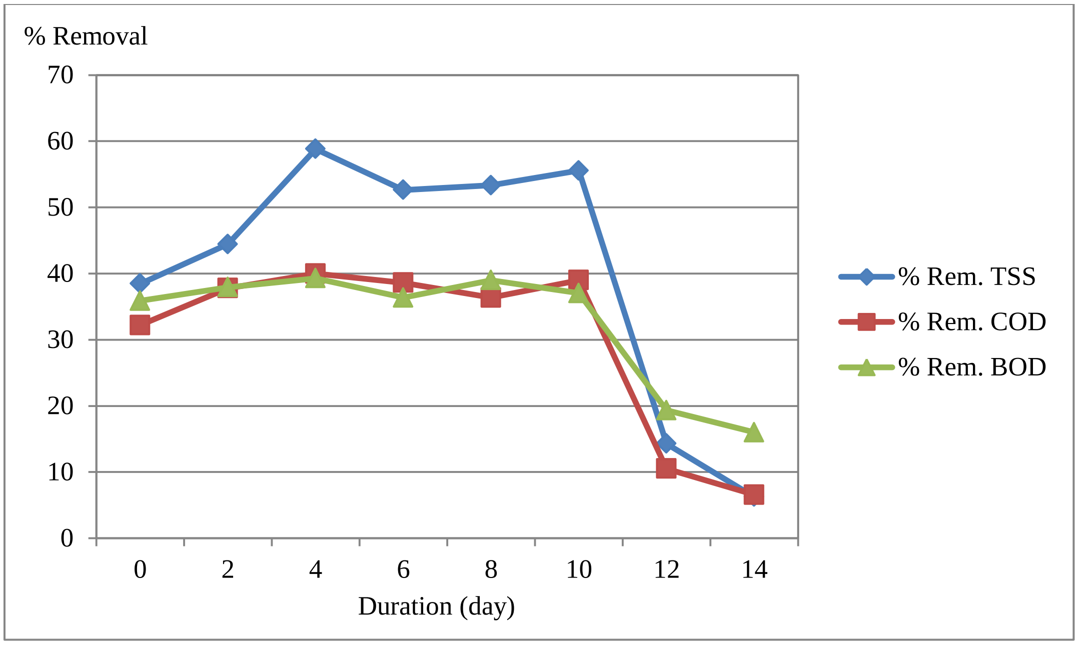

Fig. 2. *Removal efficiency of TSS, COD and BOD for Run (1).*

According to TSS measurements: Low TSS removal efficiency of 38.46 % was observed at the beginning of the run, as shown in figure (2). This is probably due to the low influent concentration of fine suspended solids, which are difficult to be retained within the voids of the filter. A gradual increase in TSS removal efficiency from 38.46 % to 58.82 % was observed after 4 days of operation. During the following 6 days of the run, the TSS removal efficiency was observed to be stabilized around 52.63 % to 55.56 %. This may be explained by the stability in biological fixation of soluble organic matter in synthesized cells (SS), which are held in the voids of the filter media. The failure of the results began after 10 days, as the media failed and this was attributed to the detection of a hole in the media.

According to COD measurements: Low initial COD removal efficiency was observed at the beginning of the run with a value equal to 32.2 %. This is due to the high influent concentration of COD. Generally, it is clear that COD removal is correlated to the COD loading. During the first 4 days of operation, a gradual increase from 32.2 % to 40 % in the COD removal efficiency was observed. This may is due to the formation of biological film on the media surface. During the following 6 days, the COD removal efficiency was observed to be stabilized around from 36.36 % to 39 %. This may be explained by the complete aerobic stabilization. The failure of the results began after 10 days, as the media failed and this was attributed to the detection of a hole in the media.

According to BOD measurements: As shown in figure (2), low initial BOD removal efficiency was observed at the beginning of the run with a value equal to 35.89 %. This is because of the available specific surface area of the media at which the microbial layer can grow. A gradual increase in the BOD removal efficiency was observed in the first 4 days from 35.89 % to 39.28 %, this was attributed to the formation of biological film attached to the media surface. During the following 6 days, the BOD removal efficiency was observed to be stabilized around 36.36 % to 39 %, due to the stability of the biological action through the filter. The failure of the results began after 10 days, as the media failed and this was attributed to the detection of a hole in the media.

3.2 Run Two

This run was operated as with run one with the change in depth of media to 16 cm. The system showed significant improvement in TSS and slight improvement in COD and BOD. The system started to deteriorate after 18 days of operation due to the appearance of a hole in the media. The results show influent, effluent and percentage removal of TSS, COD and BOD in Fig. 3.

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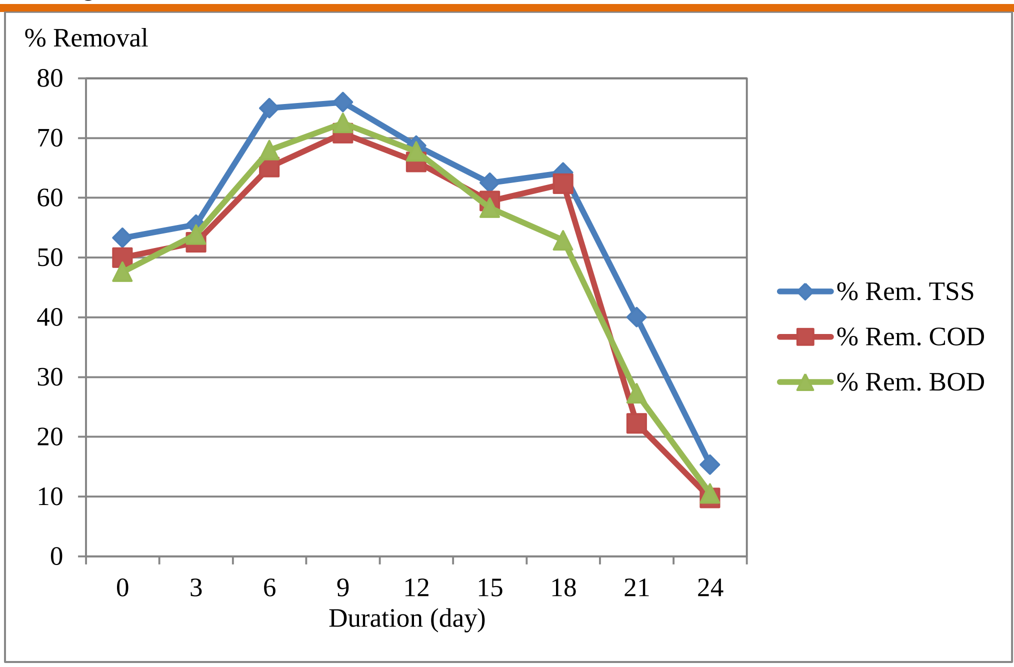

Fig. 3. *Removal efficiency of TSS, COD and BOD for Run (2).*

According to TSS measurements:It can be seen from figure (3) that low TSS removal efficiency occurs at the beginning of the run with a value equal to 53.3 % as shown. A gradual increase in TSS removal efficiency from 53.3 % to 75 % was observed during the first 6 days, this is due to the suspended solids are held in the voids between the filter media. During the following 12 days of the run, the TSS removal efficiency was observed to be stabilized around 64.2 % to 76 %. This is due to the stability in biological fixation of soluble organic matter in synthesized cells (SS), which are held in the voids of the filter media. The failure of the results began after 18 days, as the media failed and this was attributed to the detection of a hole in the media.

According to COD measurements: Low initial COD removal efficiency was observed at the beginning of the run with a value equal to 50 %. This may be because of the attachment of the biodegradable part of the COD on the large voids of the media through which the flow passes. As the wastewater flows over the media, the microbial film is being formed, the soluble organic matter is metabolized and the colloidal organic matter absorbed. During the first 6 days, a gradual increase from 50 % to 65.15 % in the COD removal efficiency was observed. This is because the formation of biological film on the media surface. During the following 12 days, the COD removal efficiency was observed to be stabilized around from 59.45 % to 70.81 %. This may be explained by the stability of the oxidation process occurred on the media surface. The failure of the results began after 18 days, as the media failed and this was attributed to the detection of a hole in the media. During the first 6 days, a gradual increase from 47.62 % to 68 % in the BOD removal efficiency was observed. This is due to the formation of biological film on the media surface.

According to BOD measurements: low initial BOD removal efficiency was observed at the beginning of the run with a value equal to 47.62 %. This is because of the large voids of the media through which the flow passes. During the first 6 days, a gradual increase from 47.62 % to 68 % in the BOD removal efficiency was observed. This is due to the formation of biological film on the media surface. During the following 12 days, the BOD removal efficiency was observed to be stabilized around 52.9 % to 72.5 %. This may be explained by the continuous sloughing of the outer slime layer after complete aerobic stabilization under the effect of flow shearing, while the inner layer is partially oxidized. This conditions lead to the stability of the removal efficiency. The failure of the results began after 18 days, as the media failed and this was attributed to the detection of a hole in the media.

3.3 Run Three

This run was operated as with the previous runs with the change in depth of media to 30 cm. The system showed significant improvement in TSS, COD and BOD. The system started to deteriorate after 27 days of operation due to the appearance of a hole in the media. The results show influent, effluent and percentage removal of TSS, COD and BOD in the following tables and figures.

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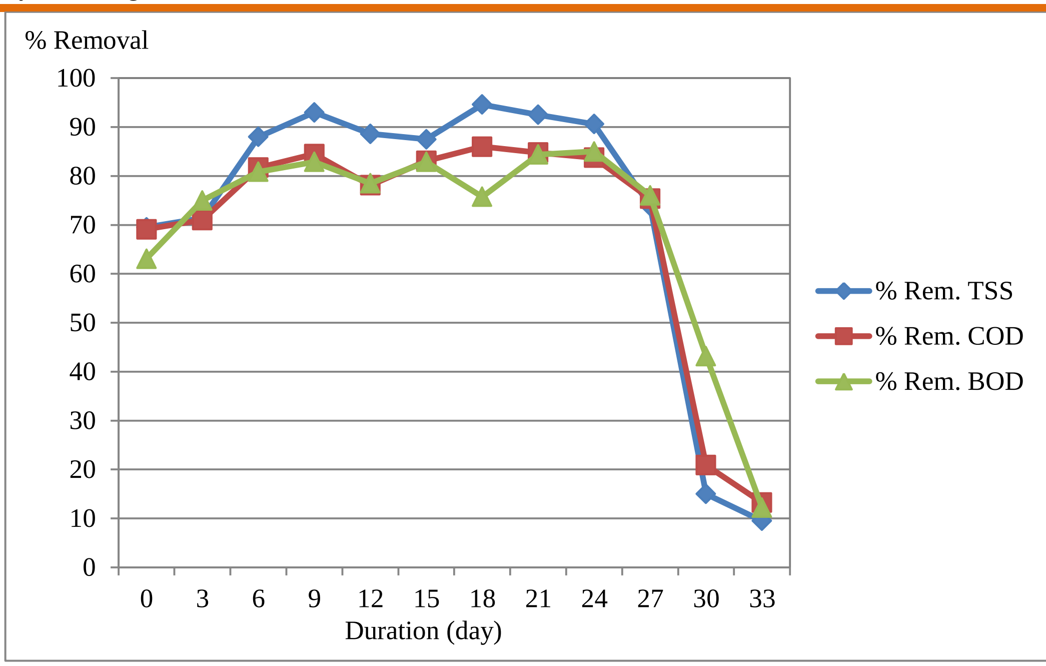

Figure (4): *Removal efficiency of TSS, COD and BOD for Run (3).*

According to TSS measurements: Low TSS removal efficiency of 69.5 % was observed at the beginning of the run, as shown in figure (4). This is probably due to the low influent concentration of fine suspended solids, which are difficult to be retained within the voids of the filter. A gradual increase in TSS removal efficiency from 69.5 % to 93 % was observed during the first 9 days. This is because the suspended solids are retained between the filter media due to the increase of oxidized suspended solid resulting from the biological action occurred through the filter on the surface area of the media. During the following 18 days of the run, the TSS removal efficiency was observed to be stabilized around 73.9 % to 94.6 %. This may be explained by the stability in biological fixation of soluble organic matter in synthesized cells (SS), which are held in the voids of the filter media. The failure of the results began after 27 days, as the media failed and this was attributed to the detection of a hole in the media.

According to COD measurements Low initial COD removal efficiency was observed at the beginning of the run with a value equal to 69.1 %. This may be because of the attachment of the biodegradable part of the COD on the large voids of the media through which the flow passes. As the wastewater flows over the media, the microbial film is being formed, the soluble organic matter is metabolized and the colloidal organic matter absorbed. During the first 9 days, a gradual increase from 69.1 % to 84.5 % in the COD removal efficiency was observed. This is due to the formation of biological film on the media surface. During the following 18 days, the COD removal efficiency was observed to be stabilized around from 81.4 % to 88.15 %. This may be explained by the complete aerobic stabilization. The failure of the results began after 27 days, as the media failed and this was attributed to the detection of a hole in the media.

According to BOD measurements: As shown in figure (4), low initial BOD removal efficiency was observed at the beginning of the run with a value equal to 63.1 %. This is because of the large voids of the media through which the flow passes. As the wastewater flows over the media, the microbial film is being formed, the soluble organic matter are metabolized and the colloidal organic absorbed. During the first 9 days, a gradual increase from 63.1 % to 82.9 % in the BOD removal efficiency was observed. This is due to the formation of biological film on the media surface. During the following 18 days, the BOD removal efficiency was observed to be stabilized around 75.75 % to 85 %. This may be explained by the continuous sloughing of the outer slime layer after complete aerobic stabilization under the effect of flow shearing, while the inner layer is partially oxidized. This conditions lead to the stability of the removal efficiency. The failure of the results began after 27 days, as the media failed and this was attributed to the detection of a hole in the media.

3.4 Comparison the Performance of the Filter with Different Media Depth and Constant Flow Rate.

Table 3: TSS, COD and BOD Average Removal Efficiency for Run 1,2 & 3

Parameter		Run 1	Run 2	Run 3
Average Removal	TSS	40.59	56.72	72.84
	COD	30.13	50.92	69.29
	BOD	32.6	50.96	69.98

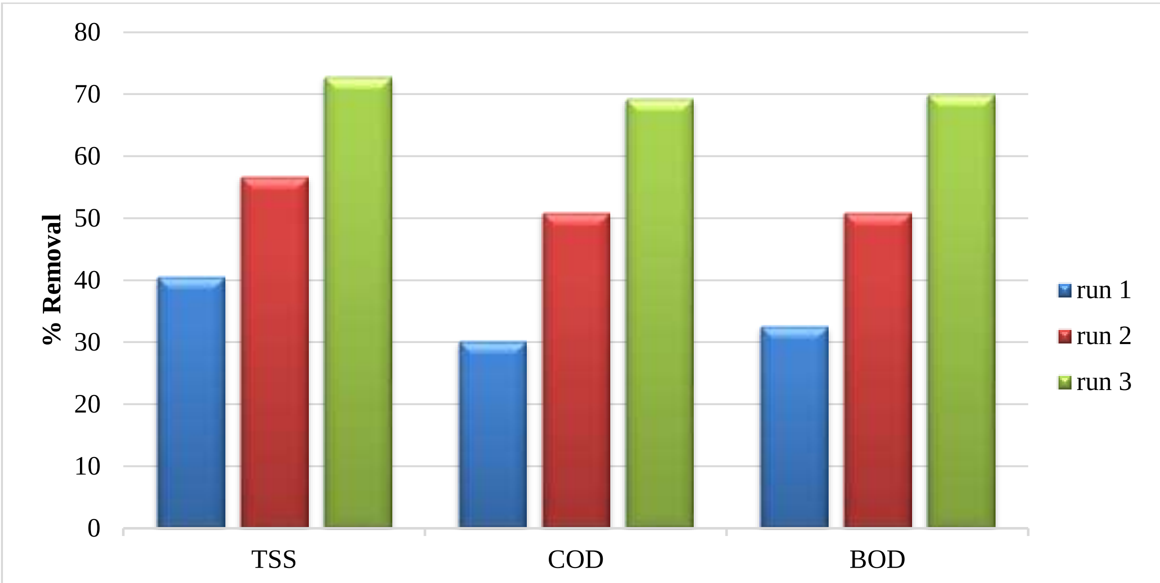

Fig. 5. *TSS, COD and BOD Average Removal Efficiency for Run 1,2 &3*

From the previous table (3) and figure (5), we can deduce that the highest removal efficiency for parameters TSS, COD and BOD was found in run 3, while the second removal efficiency was found in run 2. The lowest removal efficiency was found in run 1. The average removal efficiency in run 3 for parameters TSS, COD and BOD was 72.84 %, 69.29 % and 69.98 % respectively. While the recorded average removal efficiency for run 2 for parameters TSS, COD and BOD was 56.72 %, 50.92 % and 50.96 % respectively. Also the recorded average removal efficiency for run 1 for parameters TSS, COD and BOD was 40.59 %, 30.13 % and 32.6 % respectively. Finally, we conclude that run 3 showed the best removal efficiency compared to the other runs in the removal of the three parameters (TSS, COD & BOD). Therefore, we deduce that the depth of media of run 3 is the optimum depth that will be used in the AMTF.

4. Conclusion

Based on the study program executed in this research and the results obtained and from the previous discussion, the following conclusions were recorded: AMTF system consumes less energy and power for operating than all other systems. There is no need for artificial aeration as the oxygen is naturally continuously diffused from the cascades and ambient air into the body of pilot (reactor) creating ideal conditions for oxidation and ammonization by bacteria. The sandwich media was effective in TSS removal with an efficiency reaching 94.6 %, with an average effluent concentration up to 6 mg/l. The sandwich media was effective in COD removal with an efficiency reaching 86 %, with an average effluent concentration up to 20 mg/l. The sandwich media was effective in BOD removal with efficiency reaching 85 %, with an average effluent concentration up to 12 mg/l.

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